Texture Grouping and Statistical Optimization based Mode Prediction Decision Algorithm for Fast HEVC Intra Coding

Jianhua Wang\textsuperscript{1,2}, Feng Lin\textsuperscript{3}, Jing Zhao\textsuperscript{1,2}, Yongbing Long\textsuperscript{1,2}

\textsuperscript{*}Correspondence: wangjianhua655@163.com
\textsuperscript{1}College of Electronic Engineering, South China Agricultural University, Guangzhou, 510642, China
\textsuperscript{2}National Center for International collaboration Research on precision Agricultural Aviation, 510642, China
\textsuperscript{3}School of Computer Science and Engineering, Nanyang Technological University, 639798, Singapore

Abstract:
HEVC (High Efficiency Video Coding), as one of the newest international video coding standard, can achieve about 50% bit rate reduction compared with H.264/AVC (Advanced Video Coding) at the same perceptual quality due to the use of flexible CTU (coding tree unit) structure, but at the same time, it also dramatically adds the higher computational complexity for HEVC. With the aim of reducing the computational complexity, a texture grouping and statistical optimization based mode prediction decision algorithm is proposed for HEVC intra coding in this paper. The contribution of this paper lies in the fact that we successfully use the texture information grouping and statistical probability optimization technology to rapidly determine the optimal prediction mode for the current PU, which can reduce many unnecessary prediction and calculation operations of HCost (Hadamard Cost) and RDCost (Rate Distortion Cost) in HEVC, thus saving much computation complexity for HEVC. Specially, in our scheme, firstly we group 35 intra prediction modes into 5 subsets of candidate modes list according to its texture information of edge in the current PU, and each subset only contains 11 intra prediction modes, which can greatly reduce many traversing number of candidate mode in RMD (Rough Mode Decision) from 35 to 11 prediction modes; Secondly we use the statistical probability of the first candidate modes in candidate modes list as well as MPM selected as the optimal prediction mode to reduce the number of candidate modes in RDO (Rate Distortion Optimization), which can reduce the number of candidate modes from 3+MPM or 8+MPM to 2 candidate modes; At last, we use the number of candidate modes determined above to quickly find the optimal prediction mode with the minimum RDCost by RDO process. As a result, the computational complexity of HEVC can be efficiently reduced by our proposed scheme. And the simulation results of our experiments show that our proposed intra mode prediction decision algorithm based on texture information grouping and statistical probability optimization in this paper can reduce about 46.13% computational complexity on average only at a cost of 0.67\% bit rate increase and 0.056db PSNR decline compared with the standard reference HM16.1 algorithm.

Keywords: HEVC, Intra Mode prediction, Texture information grouping, Statistical probability optimization
1. Introduction

Aims to achieve a more high-efficient video coding rate, especially for some high-resolution video contents, such as HD (High Definition) videos, UHD (Ultra HD) videos, and so on, HEVC (High Efficiency Video Coding) [1], as one of the latest international video coding standard, have been jointly developed by the ISO/IEC MPEG (Moving Picture Experts Group) and ITU-T VCEG (Video Coding Experts Group) and JCT-VC (Joint Collaborative Team on Video Coding) [2]. HEVC mainly uses many new advanced coding technologies, such as quad-tree-based coding unit split, larger block transforms, 35 spatial intra prediction modes, adaptive entropy coding, and so on, to improve the video coding efficiency compared to some previous video coding standards, such as H.264/AVC (Advanced Video Coding). It is reported that HEVC can achieve about a 50% bit-rate reduction compared with H.264/AVC under the same perceptual video quality [3]. HEVC greatly improves the coding efficiency by using the new advanced coding technologies, but at the same time, it also hugely increases its computational complexity [4]. The new adoptions of new advanced technologies, however, will cost much more calculation time, memory consumption, and power consumption compared with H.264/AVC. The high computational complexity in HEVC has become a major obstacles for some real-time applications, such as real-time transmission and playing [5].

In HEVC, there are 35 intra prediction modes in HEVC compared with H.264/AVC, where mode 0 is for Planar, mode 1 stands for DC, and others are angular prediction modes [6]. The large increased number of intra prediction modes can result in much higher compression efficiency, but at the same time, it also leads to tremendous computational complexity because it needs to exhaustively execute the expensive RMD (Rough Mode Decision) and RDO (Rate Distortion Optimization) process to find the optimal prediction mode in a brute-force fashion, thus leads to large computational complexity for HEVC. Therefore, it is very necessary to reduce the computational complexity by improve intra prediction mode efficiency, and then improve the whole coding efficiency for HEVC [7].

To reduce the computational complexity in HEVC intra coding, many schemes have been developed to for this purpose recently. For example, a fast intra mode decision algorithm based on refinement [8], a fast intra mode decision algorithm based on edge prediction [9], a fast intra mode decision algorithm based on texture orientation detection [10], a fast intra mode decision algorithm based on early distortion estimation [11], a fast intra mode decision algorithm based on mode skipping and improved RMD [12], and so on, have been proposed to reduce its whole computational complexity for HEVC. Although these schemes above are well designed, but there is still a need to further develop more efficient intra mode prediction decision schemes to reduce its high computational complexity for HEVC.

In this paper, different from these methods above, a texture grouping and statistical optimization based mode prediction decision algorithm is proposed to reduce its many unnecessary prediction and calculation operations in HCost (Hadamard Cost) and RDCost (Rate Distortion Cost) for HEVC intra coding, thus reducing its computational complexity. The achievements of this paper include the following:

1) 35 intra prediction modes are grouped into 5 subsets of candidate modes list according to texture information of edge in the current PU, and each subset only contains 11 intra prediction modes, which can greatly reduce much unnecessary traversing number of candidate mode in RMD (Rough Mode Decision) from 35 to 11 prediction modes, thus saving much computation complexity for HEVC.

2) The statistical probability of the first candidate modes in candidate modes list as well as MPM (Most Probable Mode) selected as the optimal prediction mode to reduce the number of candidate mode in RDO (Rate Distortion Optimization),
which can reduce the number of candidate mode in RDO from 3+MPM or 8+MPM to 2 candidate modes, and then reduce much calculation complexity for HEVC.

(3) A series of experiments are performed to verify the effectiveness of our proposed method in this paper. And the simulation results show that our proposed fast mode prediction decision algorithm in this paper can reduce more coding time only at a cost of negligible bit rate increase and PSNR decline compared with some of the current processing methods.

The rest of this paper is organized as follows. In section 2, the related knowledge on intra mode prediction is introduced. Section 3 to 5 present our proposed method. The simulation result and analysis with our proposed scheme are presented in section 6. In section 7, we draw our conclusions.

2. The related knowledge on intra mode prediction

2.1 The standard realizing process of intra mode prediction

In the standard process of intra mode prediction in HEVC, three important process, RMD, MPM and RDO, as shown in Fig.1, need to go through to find the optimal prediction mode for the current encoding block. Firstly, the RMD is carried out, and 35 prediction modes are traversed. The HCost function of each prediction mode is calculated, and N best prediction modes with lower HCost value are selected into candidate list. For 4×4 and 8×8 encoding blocks, the N is 8, and for 16×16, 32×32 and the 64×64 encoding block, the N is 3. Secondly, the MPM in the adjacent space of the current encoding block are used to predict the current block, i.e. the best prediction mode of the left encoding block and the upper encoding block of the current block is used to predict the current encoding block; At the same time, it determines whether the MPM has been included in the candidate mode list of RMD. If not, the MPM of the current block is added into the candidate mode list. Finally, High-precision RDO calculation is carried out without repetition to find the best prediction mode with the minimum RDCost value from candidate mode list above.

![Figure 1: The standard realizing process of intra mode prediction](image)

2.2. Computational Complexity analysis of intra mode prediction

In the standard process of intra mode prediction decision in HEVC, since the basic prediction unit is PU, the total partition number of PU in a LCU with 64×64 is about 4⁰+4¹+4²+4³+4⁴=341. Where 4⁰ represents the number of PU in the depth 0; 4¹ represents the number of PU in the depth 1; 4² represents the number of PU in the depth 2; 4³ represents the number of PU in the depth 3; 4⁴ represents the number of PU in the depth 4.

In HEVC, since there are 35 candidate modes for each PU partition, including 33 angular modes and DC and Planar modes. If each PU in 341 needs to independently execute 35 mode prediction based on HCost calculation, HEVC will need to take 341×35=11935 times HCost, which is very time-consuming.

As the number of RDCost calculation for each PU prediction mode is determined by coding block size of PU as well as MPM, the N is 8 for 4×4 and 8×8 coding blocks, and N is 3 for 16×16, 32×32 and 64×64 coding block. Therefore the
minimum number for RDCost calculation required for different size of PU in a LCU can be calculated as follows: $4^4 \times 8 = 32 \times 8 + 4^3 \times 8 \times 4 + 4^2 \times 3 + 4^1 \times 3 + 4^0 \times 3 = 2613$, and the maximum number for RDCost calculation required for different size of PU in a LCU can be calculated as below: $4^4 \times 10 + 4^3 \times 10 + 4^2 \times 5 + 4^1 \times 5 + 4^0 \times 5 = 3305$. Therefore, in order to realize the intra mode prediction of a LCU with size of $64 \times 64$, HEVC needs to execute about $11935$ times HCost calculation operations, and at least $2613$ times, up to $3305$ times RDCost calculation operations, which is very highly complex and time-consuming.

Table 1 is are time consumption rate of RMD and RDO for six different test sequences in the full I-frame configuration with 100 coding frames. From Table 1, we can see that HEVC needs to take many HCost and RDCost calculations to obtain the optimal prediction mode for the current encoding block, which costs about $16.51\%$ and $51.46\%$ computational complexity of HEVC intra prediction, thus seriously influencing its real-time encoding efficiency for HEVC.

| Test sequences   | Resolution    | Time consumption rate in intra mode prediction |
|------------------|---------------|-----------------------------------------------|
|                  |               | RMD process | RDO process |
| Traffic          | 2560x1600     | 14.97\%     | 49.86\%     |
| Cactus           | 1920x1080     | 16.34\%     | 54.76\%     |
| BQMall           | 1280x720      | 17.31\%     | 53.79\%     |
| BlowingBubbles   | 1024x768      | 16.15\%     | 49.62\%     |
| Johnny           | 832x480       | 18.61\%     | 52.28\%     |
| Slideshow        | 416x240       | 15.66\%     | 48.44\%     |
| **Average**      |               | 16.51\%     | 51.46\%     |

**2.3. Related study of intra mode prediction**

In order to reduce the computational complexity for HEVC, many mode prediction decision algorithms based on different method have been developed recently.

In this paper [8], a fast intra mode prediction decision algorithm based on the refinement is proposed to reduce the computational complexity for HEVC, where Gao et al. mainly used the refinement of general directions and the correlation between neighbouring blocks to speed up the RMD and MPM process. In this paper [9], a fast mode prediction decision algorithm based on edge is suggested to reduce the computational complexity for HEVC intra prediction. In this article, Nat et al. used an adaptive selection based on edge map for candidate modes to reduce the number of the candidate modes in a coding block. An intra mode prediction decision method based on texture orientation detection is proposed to reduce its computational complexity for HEVC in this paper [10], where Ruiz et al. proposed a reduced set of directional candidate modes on the basis of computing the local directional variance and a set of co-lines with rational. An intra mode prediction decision algorithm based on early distortion estimation to reduce its computational complexity for HEVC in this work [11]. In their scheme, Heindel et al. mainly proposed an early estimation of the distortion with a certain mode to accelerate the intra mode selection process. In this paper [12], a fast mode prediction decision algorithm based on mode skipping and improved RMD is proposed to reduce its computational complexity for HEVC. In this paper, Lu et al. mainly used the correlation of prediction mode between adjacent quad-tree coding levels and temporal neighbouring frames to predict the most likely coding modes. A fast intra mode prediction decision algorithm based on micro-and macro-level is proposed to reduce its computational complexity for HEVC in this reference [13]. At the micro-level of the paper, they used progressive rough mode search based on HCost to selectively check the potential modes, while at the macro-level of the article, used an early coding unit split termination in its RDcost process. In the paper [14], a fast intra mode prediction decision algorithm based on matching edge detector and kernel density
estimation is proposed to reduce its computational complexity for HEVC, where they used the source image edge direction and strength features to reduce the computational complexity of both RMD and RDO process. In this article [15], a fast intra mode prediction decision method based on mode number is proposed to reduce its computational complexity for HEVC, where they realized the reduction of candidate modes in RMD from 35 to 19 modes. In the paper [16], a fast intra mode prediction decision scheme based on early termination is proposed to reduce its computational complexity for HEVC, where they used variation of coding mode costs to terminate the mode decision for current CU and TU size selection, and used neighboring modes' cost to skip some of RDO quantization. In the paper [17], Yao et al. proposed a fast intra mode prediction decision algorithm based on dominant edge assent distribution to reduce its computational complexity for HEVC. In their method, they mainly use dominant edge assent (DEA) and its distribution to reduce the rough mode decision (RMD) and rate distortion optimization (RDO) process. In this work [18], Fang et al. proposed a fast intra mode prediction decision scheme based on direction energy distribution to reduce its computational complexity for HEVC. In which they mainly make use of the energy distribution of four main directions to choose 9 or 11 modes from 33 angular modes to realize the mode decision for HEVC intra coding. In this paper [19], Shi et al. proposed a fast mode prediction decision scheme based on local saliency detection to reduce its computational complexity for HEVC, in which the statistics of RMD process and the crossing out some unlikely angular candidates are used to reduce the computational complexity. In this paper [20], a fast mode decision algorithm based on improved edge detection and SATD costs classification is proposed to reduce the computational complexity for HEVC, where spatial correlation among neighboring blocks, binary classification and RDO dodging are proposed to eliminate some candidate modes prior to rate distortion optimization (RDO) process. In this work [21], a fast mode decision algorithm based on texture characteristic is proposed to reduce the computational complexity for HEVC, where they use the texture characteristic reflected by two of the best candidate modes in RMD and MPM, to reduce the number of candidate modes in RDOQ. In the reference [23], a fast INTRA mode prediction decision algorithm based on screen content coding is proposed to reduce the computational complexity for HEVC, where intra block copy mode and palette mode were skipped for nature video content. In the reference [24], a fast mode acceleration solution, including mode clustering, short-listing, and early decision strategies, is proposed to reduce the computational complexity for HEVC. This method can reduce seven times computational complexity compared with the standard HM. In the paper [25], a fast intra mode prediction method based on random forest is suggested to reduce the computational complexity for HEVC, in which the directional feature of a block is used to reduce the number of candidate modes. In this article [26], Zhang et al. proposed a fast intra mode prediction decision based on statistical Early Termination (ET) and Early Skip (ES) models for HEVC coding, where they proposed three categories of ET and ES sub-algorithms to reduce the computational complexity for HEVC. In this article [27], Bae et al. suggested an adaptive early termination algorithm based on coding unit depth history to reduce the computational complexity for HEVC, in which the temporal correlation of co-located coding tree units (CTUs) is used to traces depth history of a CU. In this article [28], a fast intra mode prediction decision based on the pattern direction prediction from Most Probable Modes (MPM) is proposed to reduce the number of intra prediction mode candidates. In this reference [29], Shang et al. proposed to use the correlations between the higher layer prediction mode and current layer mode for the angular mode prediction in HEVC, which can reduce much computational complexity for HEVC. In this work [30], Zhang et al. proposed a progressive rough mode search method based on HCost value to search the potential modes from all 35 candidates in RMD, which can reduce the computational
complexity for HEVC. In the reference [31], a fast intra mode selection algorithm is proposed for HEVC-based 3D depth video coding, in which the spatiotemporal, inter-view correlation and inter-component neighboring coded CUs are used for the size decision of PU block. In the paper [32], a gradient-based method was proposed to reduce the candidate modes for RMD and RDO, where the joint using of Early Skip (ES) and Early Termination (ET) strategies are carried out to improve the PU size decision and prediction mode in each DL. In the paper [33], a fast intra prediction mode and CU (Coding Unit) size decision algorithm based on prediction mode and coding bits grouping is presented for HEVC intra encoding, where they mainly used the prediction mode grouping and coding bits grouping technologies to rapidly realize the optimal prediction mode and size decision for the current CU, thus saving much computation complexity for HEVC.

Although these schemes above are well designed, but there is still a need to further develop more efficient mode prediction schemes to reduce its large computational complexity for HEVC. Different from the state-of-the-art methods above, in this paper, a texture grouping and statistical probability based mode decision algorithm is proposed to reduce its computational complexity for HEVC intra coding. In our scheme of this paper, we mainly use texture grouping and statistical probability technology to quickly find the optimal prediction mode for the current coding block, which can reduce many unnecessary prediction and calculation operations of HCost and RDCost in HEVC, thus reducing much computational complexity for HEVC.

3. Proposed scheme based on texture grouping

In this section, a texture grouping and statistical optimization based mode prediction decision algorithm is proposed to reduce the computational complexity for fast HEVC intra coding.

3.1. Motivation of our proposed method

In HEVC, in order to quickly find the optimal prediction mode for each PU coding block, HEVC needs to exhaustively execute these 35 prediction modes based on HCost and RDCost calculation respectively, which can dramatically increase the computational complexity and makes the implementation of HEVC in real-time applications very difficult. However, there is strong a strong correlation between adjacent reference pixels and between adjacent angular prediction modes because of its texture continuity of video images in HEVC.

In order to reduce the computational complexity of HCost and RDCost in HEVC, in this paper, we we use the texture information grouping technology to quickly reduce the prediction mode number in RMD (Rough Mode Decision) from 35 prediction modes to 11 prediction modes based on the texture information of edge in the current PU, which can efficiently reduce much computational complexity for HEVC.

3.2. Working principle of our proposed scheme

The working principle for our proposed scheme is that: firstly we divide a PU block into 5 basic edge directions: no obvious direction, horizontal direction, vertical direction, 45°diagonal direction, 135° diagonal direction based on texture information complexity of edge for the current PU; Secondly we group 35 intra prediction modes into 5 subsets of candidate modes list according to 5 edge directions above, and each subset only includes 11 prediction modes; Thirdly we determine the edge direction of the PU block according to its pixel value among 5 edge direction above by calculating the sum of pixel values of each 2×2 in each edge direction of the PU block; At last, we select the corresponding subset of candidate mode list according to edge direction selected above. As a result, the computation complexity in HEVC can be efficiently reduced by our proposed scheme, thus improving its whole encoding efficiency.
3.3. **Realizing process of our proposed scheme**

In order to reduce the number of prediction mode in RMD, and then save computational complexity of HCost in HEVC, a RMD based on texture information grouping is proposed in this paper. In our scheme, our proposed scheme can reduce the number of prediction modes of RMD from 35 to 11 modes. Fig.2 is the realizing process for RMD based on texture information grouping of our proposed method in this paper.

![Diagram of RMD process](image)

**Figure 2. The realizing process for RMD based on texture grouping**

Fig.2 shows that our proposed RMD based on texture information grouping mainly consists of six realizing contents: divided edge direction, group prediction mode, calculate edge direction, select subsets of candidate modes, calculate HCost value and determine N candidate modes. The implementation process for them are shown as follows.

**(1) Divided edge direction**

We divided texture direction of a current PU into five edge directions. That is, no obvious edge, horizontal edge, vertical edge, 45° diagonal edge, 135° diagonal edge.

**(2) Group prediction mode**

We divided 35 intra prediction modes into 5 subsets of candidate mode list through 5 basic edge directions above, and established a mapping relationship between prediction mode subset and texture edge direction for a current PU. The following is the built mapping relationship between prediction mode subset and texture edge direction for a PU:

1. **No obvious direction mode**
   
   \[ E_{nt} = \{0,1,2,6,10,14,18,22,26,30,34\} \]

2. **Horizontal direction mode**
   
   \[ E_{h} = \{0,1,6,7,8,9,10,11,12,13,14\} \]

3. **Vertical direction mode**
   
   \[ E_{v} = \{0,1,22,23,24,25,26,27,28,29,30\} \]

4. **45° diagonal direction mode**
   
   \[ E_{45} = \{0,1,2,3,4,5,30,31,32,33,34\} \]

5. **135° diagonal direction mode**
   
   \[ E_{135} = \{0,1,14,15,16,17,18,19,20,21,22\} \]

In order to ensure the accuracy of intra prediction, intra DC mode and intra Planar mode are added into each of 5 subsets of prediction mode list above in our scheme, and the available number of candidate modes in each subsets can be reduced from 35 to 11 candidate modes, thus saving much computational complexity of HCost for HEVC.

**(3) Calculate edge direction**
Divided each PU block with 4 × 4 into 4 sub-PU blocks with 2 × 2, and each sub-PU block with 2 × 2 can be calculated by the average value of 4 pixels in it. Formula (1) to formula (4) is the calculation formula of sum pixel values for each sub-PU block with 2 × 2 in a 4 × 4 size.

\[ C_{00} = C_1 + C_2 + C_5 + C_6 \]  
\[ C_{01} = C_3 + C_4 + C_7 + C_8 \]  
\[ C_{02} = C_{09} + C_{10} + C_{13} + C_{14} \]  
\[ C_{03} = C_{11} + C_{12} + C_{15} + C_{16} \]  

Formula (5) to formula (9) are the calculation formula for each of sub-PU block with 2 × 2 size.

\[ E_{nd} = |C_{00} - C_{03}| + |C_{01} - C_{02}| \]  
\[ E_{v} = |C_{00} - C_{02}| + |C_{01} - C_{03}| \]  
\[ E_{h} = |C_{00} - C_{01}| + |C_{02} - C_{03}| \]  
\[ E_{45^\circ} = |C_{01} - C_{02}| \]  
\[ E_{iso} = |C_{00} - C_{03}| \]  

In our suggested scheme, the smaller for the value of edge direction, the high the degree of corresponding edge direction. Figure 3 is the dividing process for a PU with size of 8 × 8 in our method. As shown in Figure 3, a 8 × 8 PU block can be divided into 2 PU with 4 × 4 size, and its edge directions for each PU with 4 × 4 size can be calculated by formula (1) to (9) above.

(4) Select subsets of candidate modes

Select the corresponding subset of candidate mode list according to its calculated edge direction above. For example, the vertical subsets \( E_{v} \) is set for the current PU if the current PU is calculated as vertical prediction. If there is no obvious edge direction for the current PU, no obvious direction subsets \( E_{nd} \) is set for the current PU, and so on.

(5) Calculate HCost value

Calculate the HCost value of each prediction mode in the selected subset of candidate mode list according to the HCost method, and order them from large to small with HCost value.

(6) Determine the number of candidate modes

Determine the number of candidate modes according to its different PU size. The number of candidate modes is 3 with size of 16 × 16, 32 × 32 and 64 × 64, and is 8 with size of 8 × 8 and 4 × 4 for a PU in HEVC.
4. Proposed scheme based on statistical probability optimization

4.1 Motivation of our proposed method

In order to further reduce the computational complexity of HCost and RDCost in HEVC, a statistical optimization based mode prediction decision algorithm is proposed in this section. In this paper, we use the statistical probability optimization between the candidate mode in candidate mode list as well as MPM selected as the optimal prediction mode to reduce the prediction number of RDO, which can efficiently reduce much computational complexity for HEVC.

4.2. Working principle of our proposed scheme

The working principle for our proposed scheme is that: we use the statistical probability of the first candidate modes in candidate modes list as well as MPM selected as the optimal prediction mode to reduce the number of candidate mode in RDO(Rate Distortion Optimization), which can reduce the number of candidate mode from 3+MPM or 8+MPM to 2 candidate modes. As a result, the computation complexity in HEVC can be efficiently reduced by our proposed scheme in this paper, thus improving its whole encoding efficiency.

4.3. Realizing process of our proposed scheme

The realizing process for our proposed method in this paper can be shown in figure 4, which consists of the following three parts: Test statistics probability selected as the optimal mode in RMD, Test statistics probability selected as the optimal mode in RMD and Use joint statistical characteristics to reduce the number of RDO, where

| Test statistics probability selected as the optimal mode in RMD | Test statistical probability selected as the optimal mode in MPM | Use joint statistical characteristics to reduce the number of RDO |
|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|

Figure 4. The realizing process for our method

(1) Test statistics probability selected as the optimal mode in RMD

During the RMD process in HEVC, since the selected N candidate modes in candidate mode list are arranged with HCost value from small to large. That is that the candidate mode with the smallest HCost value is firstly placed in the first position of candidate mode list; the second candidate mode with lower HCost value is put in the second position; the third candidate mode with the third lower HCost value followed, and so on.

Since the prediction mode with the minimum HCost value is generally the optimal prediction mode in HEVC. Therefore, the first prediction mode in the candidate mode list is highest probability to select as the optimal prediction mode, the second candidate mode next, the third candidate mode followed, and so on. Based on the principle above, we test the statistical probability for the first to third candidate modes to select as the optimal prediction mode from 12 different test sequences aforementioned in our experiment. Table 2 is the statistical probability for the first to third candidate modes selected as the optimal prediction mode from 12 different test sequences.

| Picture Size | Sequences name | Statistical probability for the first candidate mode selected as the optimal prediction mode (%) | Statistical probability for the second candidate mode selected as the optimal prediction mode (%) | Statistical probability for the third candidate mode selected as the optimal prediction mode (%) |
|--------------|----------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|

Table 2. The statistical probability for the first to third candidate modes in RMD selected as the optimal prediction mode
From table 2, we can see clearly that the average statistical probability for the first candidate mode selected as the optimal prediction mode is very high, reaching to about 76%. The average probability for the second and the third candidate mode selected as the optimal prediction mode drops are dropped to 12% and 4% respectively. Therefore, based on the phenomenon above, in this paper, we can use the high statistical probability of the first candidate mode selected as the optimal prediction mode to effectively reduce the number of prediction modes of RDO, thereby reducing the computational complexity for HEVC.

(2) Test statistical probability selected as the optimal prediction mode of MPM

In HEVC, after determining the number of RMD, HEVC needs to add the MPM of current PU block into candidate mode list to predict the optimal prediction mode. In our scheme, in order to further reduce the total number of RDO, we also test statistical probability for MPM selected as the optimal prediction mode. Table 3 is the statistical probability for MPM selected as the optimal prediction mode.

| Picture Size | Sequences name | Statistical probability for MPM[1] selected as the best prediction mode | Statistical probability for MPM[2] selected as the best prediction mode |
|--------------|----------------|------------------------------------------------------------------------|------------------------------------------------------------------------|
| Class A      | Cactus         | 0.84                                                                   | 0.068                                                                   |
|              | ParkScene      | 0.82                                                                   | 0.064                                                                   |
| Class B      | BQMall         | 0.80                                                                   | 0.061                                                                   |
|              | PartyScene     | 0.78                                                                   | 0.067                                                                   |
| Class C      | BlowingBubbles | 0.84                                                                   | 0.065                                                                   |
|              | BQSquare       | 0.80                                                                   | 0.068                                                                   |
| Class D      | Johnny         | 0.88                                                                   | 0.059                                                                   |
|              | KristenAndSara | 0.91                                                                   | 0.063                                                                   |
| Class E      | Slideshow      | 0.83                                                                   | 0.062                                                                   |
|              | Slideshow      | 0.79                                                                   | 0.057                                                                   |
| Class F      | Cactus         | 0.80                                                                   | 0.068                                                                   |
|              | ParkScene      | 0.89                                                                   | 0.063                                                                   |
| Average      |                | 0.83                                                                   | 0.063                                                                   |
From Table 3, we can also see clearly that the average statistical probability for the first MPM selected as the optimal prediction mode is also very high, reaching to 83%, while the statistical probability for the second MPM select as the best prediction mode is very low, only 6.3%. Therefore in this paper, we can also use the statistical probability of the first MPM selected as the optimal prediction mode to effectively reduce the total number of prediction modes in RDO, thereby reducing the computational complexity for HEVC.

(3) Use joint statistical characteristics to reduce the number of RDO

Based on the analysis above, in this paper, we use the probability of the first candidate mode as well as MPM selected as the optimal prediction mode to reduce the number of candidate mode in RDO for HEVC, and then reduce its computational complexity. Especially, in our proposed method, we select the first candidate modes in candidate mode list and the first MPM as the candidate modes for RDO process, which can reduce the number of candidate modes in RDO from N+MPM in standard HM algorithm to 2 in our scheme, thus reducing much computational complexity for HEVC. Table 4 the number of candidate mode in RMD, MPM and RDO between our scheme and standard HM algorithm.

| Compared method                  | The number of RMD | The number of MPM | The number of RDO |
|---------------------------------|------------------|------------------|------------------|
| Standard HM algorithm           | 35               | MPM              | 3+MPM            |
| Our proposed scheme             | 9 or 13          | 1                | 2                |

5. Hybrid scheme based texture grouping and statistical optimization

5.1. Working composition structure of our proposed algorithm

Fig.5 is the Hybrid working composition structure of our proposed method in this paper, which mainly includes three working contents: RMD based on texture information grouping, RDO based on statistical probability optimization and determine the optimal prediction mode.

Where RMD based on texture information grouping mainly use the texture information grouping technology to reduce the number of prediction mode in RMD; RDO based on statistical probability optimization mainly use the statistical probability between the candidate mode list as well as MPM selected as the optimal prediction mode to reduce the prediction number of RDO; Determine the optimal prediction mode based on candidate modes determined mainly realize the search of the optimal prediction mode by using candidate modes determined in RDO process.

Execut the RDCost calculation with the two prediction modes to determine the optimal prediction mode with the minimum RDCost value. In our scheme, we use the first candidate modes in candidate mode list and the first MPM as the candidate modes for RDO process, which can reduce the number of candidate mode in RDO from 3+MPM or 8+MPM to 2, and then find the optimal prediction mode for HEVC.

5.2. Realizing steps of our proposed algorithm
Fig.86 is the whole realizing flow of our proposed method in this paper, which includes eleven main realizing processes: divide texture direction, group candidate mode, calculate texture direction, determine texture direction, select subset of candidate mode, calculate HCost value, select the optimal candidate mode, add MPM, select the optimal MPM, execute RDCost calculation, find the optimal candidate mode. And its detailed realizing steps can be summed up the following steps:

Step 1: Divide a PU into 5 basic edge direction according to texture of PU block, no obvious direction $E_{ND}$, horizontal direction $E_H$, vertical direction $E_V$, $45^\circ$ diagonal direction $E_{45^\circ}$, $135^\circ$ diagonal direction $E_{135^\circ}$;

Step 2: Group 35 intra prediction modes into 5 subsets of candidate mode list according to 5 basic edge directions above;

Step 3: Calculate the 5 edge direction value for the current PU block according to formula (5) to formula (9);

Step 4: Determine the edge direction of the current PU block according to the value of edge direction above;

Step 5: Select the corresponding subset of candidate mode list according to the corresponding edge direction value above;

Step 6: Calculate their HCost value and order them by their HCost value from large to small in candidate mode list;

Step 7: Select the first candidate modes in candidate mode list as the candidate modes for RDO process according to the statistical probability of the first candidate modes selected as the optimal prediction mode;

Step 8: Add the MPM of current PU block into the candidate mode list;

Step 9: Select the first MPM as the candidate modes for RDO process according to the statistical probability of MPM selected as the optimal prediction mode;

Step 10: Execute the RDCost process with the number of candidate mode in candidate mode list determined by joint statistical characteristics above;

Step 11: Find the optimal candidate mode with the minimum RDCost value for current PU block;

6. Experimental results and analysis

In order to verify the performance of our proposed method above, some experiments are taken in this section. In our experiment, our designed experiments mainly includes the following two parts: build experimental environment and test experimental results in different conditions.

6.1. Build experimental environment

Our simulation environment was conducted on Inter(R) Core(TM) i7–5500 CPU @ 2.4. GHz and 4GB RAM, Windows 7 64-bit operating system. The test conditions and configurations in our experiment are built based on the JCT-VC[35]. Eighteen different test sequences are used to test the performance of our proposed method in our experiment. These selected eighteen
test sequences come from six different classes with different resolutions: Class A(2560 × 1600), Class B (1920 × 1080), Class C (832 × 480), Class D (416 × 240), Class E (1280 × 720) and Class F (416 × 240). The frame rate and frame number of these test sequences are set to 25 and 100 respectively. Table 5 is the parameters of 18 different test sequences. Other some general configuration parameters are listed in Table 6.

Table 5. Parameters of 18 different test sequences in our experiment

| Picture Size | Test sequences          | Resolution | Frame rate | Frame number |
|--------------|-------------------------|------------|------------|--------------|
| Class A      | PeopleOnstreet          | 2560×1600  | 25         | 100          |
|              | Traffic                 | 2560×1600  | 25         | 100          |
|              | BQ Terrace              | 2560×1600  | 25         | 100          |
| Class B      | BasketballDrive         | 1920×1080  | 25         | 100          |
|              | Cactus                  | 1920×1080  | 25         | 100          |
|              | ParkScene               | 1920×1080  | 25         | 100          |
| Class C      | RaceHorses              | 1280×720   | 25         | 100          |
|              | BQMall                  | 1280×720   | 25         | 100          |
|              | PartyScene              | 1280×720   | 25         | 100          |
| Class D      | BasketballPass          | 1024×768   | 25         | 100          |
|              | BlowingBubbles          | 1024×768   | 25         | 100          |
|              | BQ Square               | 1024×768   | 25         | 100          |
| Class E      | Four people             | 832×480    | 25         | 100          |
|              | Johnny                  | 832×480    | 25         | 100          |
|              | KristenAndSara          | 832×480    | 25         | 100          |
| Class F      | BasketballDrillText     | 416×240    | 25         | 100          |
|              | Slideshow               | 416×240    | 25         | 100          |
|              | China Speed             | 416×240    | 25         | 100          |

Table 6. Other some configuration parameters

| Profile                  | Main                        |
|--------------------------|-----------------------------|
| Gop Structure            | Low Delay                   |
|                          | Random access               |
| Max CU size              | 64×64                       |
| Max CU depth             | 4                           |
| Motion Search Mode       | TZ search                   |
| Motion Search Range      | 64                          |
| QP                       | 22, 27, 32, 37              |
| Encoder.cfg              | encoder_intra_main.cfg      |
| Video frame              | I frame                     |
| Reference Software Profile [34] | HM16.1                      |

In our experiment, three general test indicators, BDBR (Bjontegaard Delta Bit Rate), BDPSNR (Bjontegaard Delta Peak Signal-to-Noise Ratio) and TS (coding time saving), are used to evaluate the performance for our proposed algorithm. They can be expressed as follows.

\[
\text{BDBR} = \frac{\text{The processed or transmitted data}}{\text{a unit time}}
\]
In our experiment, four mode prediction decision methods, Mohammadreza's scheme[21], Liao's scheme[34], Chen's scheme[35] and our proposed scheme, are test for the performance of BDBR, BDPSNR and TS, compared with the standard HM16.1algorithm[36]. Where Mohammadreza's scheme mainly uses improved edge detection and SATD costs classification to reduce the computational complexity for HEVC; Liao's scheme mainly uses the depth information as well as adjusted MPM, to reduce the computational complexity for HEVC; Chen's scheme mainly uses the depth range prediction and mode reduction to save the computational complexity for HEVC, while our proposed method mainly uses texture grouping and statistical probability technology to reduce the computational complexity for HEVC. The experimental results are shown as follows.

6.2. Test experimental results

1) Test sub-algorithm of our proposed algorithm

In this subsection, we mainly evaluate the performance in each sub-algorithm of our proposed algorithm from the BDPSNR, BDBR, and TS by encoding the six standard test sequences under the same ALL INTRA configuration and four QPs. Table 7 shows the comparison results in our proposed two sub-algorithms (presented in Sections 3) compared with the standard reference HM16.1method.

Table 7 shows that, our proposed RMD based on texture information grouping (in Section 3) can reduce about 22.56% computational complexity, at a cost of 0.51% bit rate increase and 0.026 db DBPSNR decline on average respectively. And our proposed RDO based on statistical probability optimization (in Section 3) can achieve 38.07% complexity reduction, while with the increase of 0.63% BDBR and the reduction of 0.037dB BDPSNR compared with the standard HM model under the same test conditions.

The main reason for them are that, in our proposed method of RMD based on texture information grouping, we mainly use the texture information grouping technology to quickly reduce the prediction mode number in RMD, which can reduce the number of prediction mode from 35 to 11, therefore saving 22.56% computational complexity for HEVC, but at the same time, it needs to increase about 0.51% bit rate and decline 0.037 db DBPSNR as a cost. The reason for that the method of RDO based on statistical probability can saving about 28.07% computational complexity for HEVC lies in the use of the statistical probability between the candidate mode in candidate mode list as well as MPM selected as the optimal prediction mode in our proposed method, which can reduce many unnecessary number of candidate modes in RDCost for HEVC from N+MPM in standard HM algorithm to 2 in our scheme, thus saving about 28.07% computational complexity for HEVC, but at the same time, it also needs a cost of 0.63% BDBR increase and 0.032dB BDPSNR reduction compared with the standard reference HM16.1method.

| Sequences | RMD based on texture information grouping (Section 3) | RDO based on statistical probability optimization (Section 4) |
|-----------|-----------------------------------------------------|---------------------------------------------------------------|
### 2) Test comprehensive algorithm of our proposed scheme

In this subsection, we mainly test the performance of BDBR, BDPSNR, TS in different test sequences compared with the standard reference HM16.1 model. The testing results are shown in table 8.

| Picture Size | Sequences       | Our scheme vs HM | Mohammadreza's scheme vs HM | Liao's scheme vs HM | Chen's scheme vs HM |
|--------------|-----------------|------------------|-----------------------------|---------------------|---------------------|
|              |                 | BDBR  | BDPSNR | TS     | BDBR  | BDPSNR | TS     | BDBR  | BDPSNR | TS     | BDBR  | BDPSNR | TS     |
| Class A      | PeopleOnstreet  | +0.62 | -0.051 | -44.73 | +0.48 | -0.054 | -28.86 | +0.77 | -0.033 | -30.54 | +0.51 | -0.048 | -42.11 |
|              | Traffic         | +0.51 | -0.046 | -45.54 | +0.39 | -0.051 | -26.54 | +0.66 | -0.045 | -32.06 | +0.48 | -0.054 | -41.54 |
|              | BQ Terrace      | +0.72 | -0.074 | -44.82 | +0.63 | -0.065 | -28.83 | +0.73 | -0.051 | -34.72 | +0.76 | -0.067 | -40.77 |
| Class B      | BasketballDrive | +0.77 | -0.058 | -46.27 | +0.47 | -0.042 | -27.62 | +0.91 | -0.042 | -30.83 | +0.63 | -0.061 | -40.22 |
|              | Cactus          | +0.66 | -0.049 | -44.38 | +0.48 | -0.038 | -29.31 | +0.84 | -0.054 | -29.95 | +0.61 | -0.065 | -42.87 |
|              | Park Scene      | +0.81 | -0.063 | -45.89 | +0.60 | -0.074 | -28.95 | +0.74 | -0.046 | -28.15 | +0.82 | -0.074 | -40.64 |
| Class C      | Race Horses     | +0.54 | -0.045 | -46.12 | +0.66 | -0.035 | -28.19 | +0.95 | -0.038 | -30.11 | +0.69 | -0.071 | -44.23 |
|              | BQMall          | +0.67 | -0.047 | -44.81 | +0.72 | -0.042 | -27.43 | +0.82 | -0.032 | -33.24 | +0.72 | -0.062 | -41.63 |
|              | Party Scene     | +0.76 | -0.059 | -46.56 | +0.86 | -0.056 | -27.9 | +0.72 | -0.051 | -29.95 | +0.78 | -0.078 | -40.35 |
| Class D      | BasketballPass  | +0.69 | -0.056 | -46.22 | +0.56 | -0.054 | -28.69 | +0.83 | -0.045 | -28.62 | +0.63 | -0.064 | -40.51 |
|              | Blowing Bubbles | +0.63 | -0.049 | -47.63 | +0.48 | -0.062 | -29.54 | +0.96 | -0.032 | -29.93 | +0.78 | -0.065 | -41.05 |
|              | BQS Square      | +0.78 | -0.062 | -46.57 | +0.74 | -0.048 | -29.38 | +0.76 | -0.040 | -31.06 | +0.71 | -0.073 | -43.62 |
| Class E      | Four people     | +0.58 | -0.049 | -46.54 | +0.44 | -0.046 | -26.91 | +0.77 | -0.038 | -33.53 | +0.72 | -0.071 | -42.23 |
|              | Johny           | +0.61 | -0.057 | -44.22 | +0.71 | -0.039 | -28.85 | +0.81 | -0.029 | -29.56 | +0.65 | -0.058 | -40.36 |
|              | KristenAnd Sara | +0.72 | -0.065 | -48.01 | +0.84 | -0.057 | -27.88 | +0.82 | -0.050 | -31.39 | +0.86 | -0.061 | -41.21 |
| Class F      | BasketballDrift | +0.64 | -0.055 | -48.86 | +0.47 | -0.043 | -27.44 | +0.88 | -0.043 | -31.87 | +0.57 | -0.052 | -42.87 |
|              | Slideshow       | +0.57 | -0.051 | -45.54 | +0.62 | -0.053 | -26.95 | +0.72 | -0.037 | -30.14 | +0.51 | -0.054 | -41.52 |
|              | China Speed     | +0.69 | -0.063 | -47.66 | +0.74 | -0.061 | -29.81 | +0.91 | -0.052 | -33.54 | +0.91 | -0.069 | -40.93 |
| Average      |                 | +0.67 | -0.056 | -46.13 | +0.61 | -0.051 | -28.28 | +0.81 | -0.042 | -31.06 | +0.69 | -0.070 | -41.59 |
From Table 8, we can clearly see that our proposed method in this paper has whole good performance in four schemes, which can save about 46.13% coding time only at a cost of 0.67% BDBR increase and 0.056db BDPSNR decline compared with the standard reference HM16.1algorithm. Chen's scheme and Liao's scheme follows. Chen's scheme can save about 41.59% coding time, while the increase of BDBR and the decline of BDPSNR are 0.69% and 0.070 db respectively, while Liao's scheme can achieve about 31.06% coding time saving rate with a cost of 0.81% BDBR increase and 0.042 db BDPSNR decline. Mohammadreza's scheme show the worst experimental performance in four methods, only saving about 28.28% coding time, but it increases about 0.61% BDBR and decline about 0.051db BDPSNR under the same test conditions.

The main reasons for them are that, in our proposed method, we mainly use the texture information grouping and statistical probability optimization technology to realize the intra mode prediction process for HEVC, which can reduce many unnecessary prediction and calculation operations in HCost and RDCost for HEVC, therefore saving lots of computational complexity for HEVC compared with the standard reference HM16.1method. Chen's scheme use of depth range prediction and mode reduction to speed up the realizing of intra mode prediction process for HEVC in its scheme, therefore saving about 41.59% coding time, but it increases 0.69% BDBR and declines 0.070db BDPSNR. Liao's scheme uses the depth information as well as the adjusted MPM to reduce the candidate modes for the RMD and RDO process in HEVC, thus saving about 31.06% coding time for HEVC, but with a cost of 0.81% BDBR increase and 0.042db BDPSNR decline. Mohammadreza's scheme eliminates many candidate modes for RDO by the use of the improved edge detection and SATD costs classification in its scheme, but this scheme only achieves about 28.28% reduction of coding time for HEVC, with a cost of 0.61% BDBR increase and 0.051db BDPSNR decline.

3) Test algorithm performance in different QP value and test sequences
In this subsection, we mainly evaluate the performance of BDBR, BDPSNR and TS in different QP value and test sequences respectively. The related testing results are shown as follows.

![Figure 7: BDBR in different QP value for Johnny sequence](image1)

![Figure 8: BDBR in different test sequence](image2)
Fig. 7 and Fig. 8 is the performance of BDBR in different QP value and test sequences. From Fig. 7 to Fig. 8, we can clearly see that Mohammadreza’s can achieve the least increase of BDBR in different QP value and test sequence compared with standard reference HM16.1algorithm, only increase about 0.061% BDBR. Our proposed method followed, which add about 0.067% BDBR. Chen’s scheme next. It increase about 0.069% BDBR for HEVC. Liao’s scheme shows the most increase of BDBR, reaching about 0.81% BDBR for HEVC. Fig. 9 and Fig. 10 is the performance of BDPSNR in different QP value and test sequences. Fig. 9 and Fig. 10 present that Liao’s scheme can achieve the least reduction of BDPSNR with different QP value and test sequences compared with standard reference HM16.1algorithm, only decrease about 0.042db BDPSNR. Mohammadreza's scheme and our proposed method followed, which cut down about 0.051db and 0.056db BDPSNR for HEVC respectively.
Chen's scheme presents the most reduction of BDPSNR performance in four methods, reaching about 0.070db reduction for HEVC. Fig.11 to Fig.12 are the related testing results of TS in different QP and test sequences respectively. From Fig.13 to Fig.14, we can also observe see that our proposed method can realize the most saving of TS in four methods above compared with standard reference HM16.1 algorithm under the same test conditions, reaching about 46.13% coding time saving rate. Chen's scheme and Liao's scheme followed, which save about 41.59% and 31.06% coding time for HEVC respectively. Mohammadreza's method shows the least saving performance in TS, only saving about 28.28% coding time for HEVC. The similar phenomenon as that above can be found from other test sequences.

From Fig. 7 to Fig.12 above, we can also observe that the BDBR, BDPSNR and TS in four algorithm presents to slightly rise with the increase of QP value, which shows that four methods need to cost more BDPSNR and BDPSNR and can save more TS in high lower QP value compared to lower QP value under the same test conditions. The main reason for them are that, one the one hand, the four fast mode prediction algorithms above have a different impact on different QP value, thus having different BDBR, BDPSNR and TS performance compared to the standard reference HM16.1 algorithm; on the other hand, the four different methods has different processes to the different texture distributions in different test sequence, thus lead to different BDBR, BDPSNR and TS performance compared to the standard reference HM16.1 algorithm. All these studies above prove that our proposed scheme in this paper is very effective to different video coding content.

6.3 Discussion

Although this method can reduce lots of computational complexity with less BDBR increase and BDPSNR decline for HEVC compared with the standard reference of HM16.1, it is not suitable for some high real-time embedded devices. This is because these devices require lower power consumption. However, as a fast mode decision optimal algorithm, our proposed uses texture information grouping and statistical probability optimization technologies to quickly determine the optimal partition mode for the current CU, which can reduce many unnecessary partition and prediction operations, thereby saving much computational complexity for HEVC and suiting for some general real-time embedded devices.

7. Conclusion and future work

In this paper, a texture information grouping and statistical probability optimization based fast intra mode decision algorithm is proposed to reduce unnecessary prediction and calculation operations in HCost and RDCost for HEVC, and thereby reducing its whole computational complexity. In our scheme, we firstly use the texture information grouping technology to effectively reduce the number of candidate mode in RMD (Rough Mode Decision); then we use the statistical probability between the first candidate modes as well as MPM selected as the optimal prediction mode to further reduce the number of candidate modes in RDO; at last, we use by the candidate modes determined by above to quickly find the optimal prediction mode with the minimum RDCost value. As a result, our proposed algorithm can reduce much computational complexity for HEVC. The simulation results show that our proposed fast intra mode decision algorithm in this paper can reduce about 46.13% computational complexity on average, only add 0.67% bit rate and decline 0.056db BDPSNR compared with the standard reference HM16.1algorithm. We plan to continue our future research in the following two directions. Firstly, we will extend our proposed method to suit the processing for inter mode prediction. Secondly, we will incorporate Bayes' theory and machine learning in our proposed to improve its whole performance for HEVC.

Acknowledgment
The work was supported by the National Natural Science Foundation of China (No. 61602187) and (No. 61601189), the National Key Research and Development Plan (No. 2016YFD0200700); the science and technology projects in Guangdong Province (No. 2016A020209007) and (No. 2016A020210088).

**Abbreviations**

HEVC: High Efficiency Video Coding; CTU: Coding Tree Unit; CU: Coding Unit; LCU: Large Coding Unit; QP: Quantitative Parameter; MPEG: Moving Picture Experts Group; VCEG: Video Coding Experts Group; HD: High Definition; UHD: Ultra High Definition; RD Cost: Rate-Distortion Cost; CU: Coding Unit; DC: Direct Current; DTV: Discretization Total Variation; SATD: Sum of Absolute Transformed Differences; CNN: Convolution Neural Network; BDBR: Bjontegaard Delta Bit Rate; BDPSNR: Bjontegaard Delta Peak Signal-to-Noise Ratio; TS: Coding Time Saving;

**Authors’ contributions**

Jianhua Wang, Feng Lin found the idea and wrote this article, Jing Zhao, Yongbing Long put forward some constructive suggestions for revision. The authors read and approved the final manuscript.

**Availability of data and materials**

Not applicable.

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare that they have no competing interests.

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