MODE DEPENDENT INTRA SMOOTHING FILTER FOR HEVC

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ABSTRACT

High efficiency video coding (HEVC) is the latest video coding standard, in which coding performance improvement of intra prediction comes from flexible block partitioning and advanced directional prediction. Blocks with strong directionality and regular patterns can be handled well by this finer granular directional prediction. However, irregular patterns and noises often exist in natural videos, and reference samples are not fully used in directional intra prediction. In this paper, we propose a mode dependent intra smoothing filter algorithm to improve intra prediction, which employs a Markov model to improve coding efficiency of intra prediction. Experimental results demonstrate that the proposed method can achieve average 1.1% (up to 1.8%) BD-rate reduction in all intra high efficiency test condition compared to HM 16.0.

Index Terms— Video coding, HEVC, intra prediction, smoothing filter

1. INTRODUCTION

High efficiency video coding (HEVC) [1], developed by the Joint Collaborative Team on Video Coding (JCT-VC), provides equivalent subjective quality with about 50% bit rate reduction compared to H.264/AVC High Profile [2]. The significant coding gain comes from flexible recursive block partitioning, finer granularity prediction, enhanced transformation and quantization, and improved entropy coding in HEVC, among of which, finer granularity prediction plays an important role in intra prediction [3]. HEVC includes 35 intra prediction modes, consisting of a DC mode, a Planar mode, and 33 directional intra prediction modes. This directional intra prediction deals with regular blocks well, but it often results in non-smooth and unnatural patterns which makes the prediction residue not transform-friendly [4]. To solve this problem, recently both improving accuracy of prediction and post processing methods have been proposed.

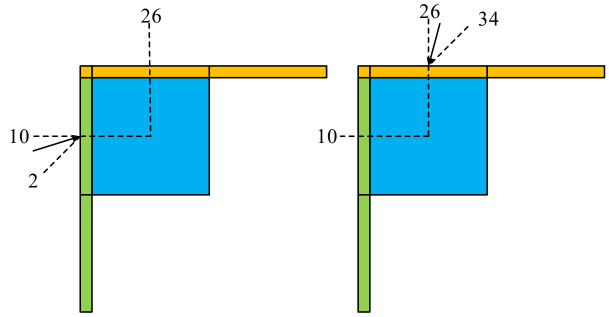
L. Liu *et al*. proposed a context-adaptive linear prediction method in [5] and a weights determination approach based on a statistical model of image pixels was presented in [6]. Template matching prediction (TMP) method was proposed and improved in [7]-[9], wherein reconstructed neighboring pixels were used as templates to search for the best prediction candidates. F. Kamisli modeled image pixels with a Markov process and proposed an alternative approach of intra prediction [10]. Y. Chen *et al*. approximated the image signal by a 2-D non-separable Markov model and proposed a novel intra prediction scheme based on recursive extrapolation filters [11]. Then S. Li *et al*. improved the recursive extrapolation scheme using rate distortion optimization and adaptation of filter parameters [12]. Above algorithms mainly focus on improving accuracy of intra prediction. L. Zhang *et al*. proposed a position-dependent filter algorithm to eliminate the spatial redundancies [13]. A multi-parameter intra prediction method was proposed in [14], in which the predicted pixels were filtered by one of 3 filters, which was chosen by rate distortion optimization (RDO).

Most of above algorithms make encoding complexity of HEVC increase dramatically, which cannot reach good trade-off between complexity and compression efficiency. In addition, as fast algorithms are essential for HEVC in practical applications. Directional information of a block represented by intra prediction mode is often used in these fast algorithms. However, this consideration is nearly ignored in above algorithms. In this paper, we propose a mode dependent intra smoothing filter (MDISF) algorithm to improve intra prediction of HEVC, which employs a Markov model to smooth the predicted pixels with an acceptable complexity increasing. Furthermore, the directional information of the block is reserved and is helpful for complexity reduction.

The rest of this paper is organized as follows. Section 2 introduces our motivation and points out the problem. Section 3 describes the proposed algorithm in detail. Experimental results and analysis are shown in Section 4 and conclusions are provided in Section 5.

2. PROBLEM STATEMENT

Intra prediction modes consists of a DC mode, a Planar mode, and 33 directional modes, which copy boundary pixels (or linear combinations thereof) along certain directions. However, this technology ignores the inter-pixel correlation along other directions. For example, as shown in Fig. 1 (a), when the mode number is larger than 26 (VER_IDR), only above boundary pixels (denoted by yellow) are used as reference samples and left boundary pixels (denoted by green) are useless. Similarly, as shown in Fig.1 (b), when the mode number is smaller than 10 (HOR_IDR) and not smaller than 2, only left boundary pixels are used as reference samples and above boundary pixels are useless.



(a) (b)

Fig. 1. Directional prediction in HEVC.

Besides, directionality is not always obvious and strong in natural videos, thus directional intra prediction results in unnatural patterns that make the prediction residue not transform-friendly. Directional information is helpful for fast algorithms and other applications. Many algorithms lost directional information when improving compression efficiency of intra prediction. And conventional smoothing filters tend to also remove meaningful details from the predicted signals. The proposed mode dependent intra smoothing filter method not only improves coding performance of intra prediction, but also reserves the directional information of a block.

3. PROPOSED METHOD

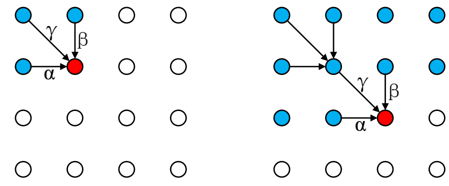
3.1. Methodology

Similar to [11], intra prediction can be considered as a 2-D non-separable Markov model with zero-mean and unit variance. As shown in Fig. 2, the red circle denotes the pixel that is going to be predicted, and the blue ones denote pixels which have been predicted, and the white ones denote pixels that have not been predicted. Fig. 2 (a) shows the process of one pixel being predicted. All predicted pixels are generated by a recursive 2-D non-separable Markov process as shown in Fig. 2 (b). The evolution recursion can be written as follows:

$$P_{i,j} = \alpha P_{i,j-1} + \beta P_{i-1,j} + \gamma P_{i-1,j-1} + \varepsilon \quad (1)$$

Where $P_{i,j}$ denotes current pixel. $P_{i,j-1}$, $P_{i-1,j}$, and $P_{i-1,j-1}$ denote neighboring pixels which have been predicted. α, β, and γ denote weighted parameters for different neighboring pixels respectively. ε is an offset.

We can see that only neighboring pixels are used to predict the current pixel, since current pixel is unknown. Benefit from directional intra prediction of HEVC, all pixels in a block can be predicted together. Thus we can use predicted signals from directional intra prediction to refine the non-separate Markov process.



(a) (b)

Fig. 2. Recursive Markov process.

In another word, directional intra prediction is applied at first, and then the modified non-separate Markov process is applied, which also takes current pixel as reference. Thus (1) can be rewritten as (2).

$$P'_{i,j} = \alpha P'_{i,j-1} + \beta P'_{i-1,j} + \gamma P'_{i-1,j-1} + \delta P_{i,j} + \varepsilon \quad (2)$$

The symbols are defined as similar as (1). Differently, $P_{i,j}$ is produced by directional intra prediction. Besides, as shown in Fig. 2 (b), influence on the current pixel from left-above pixel in the Markov model can be represented by combination left pixel and above pixel. So (2) can be simply rewritten as (3).

$$P'_{i,j} = \alpha P'_{i,j-1} + \beta P'_{i-1,j} + \delta P_{i,j} + \varepsilon \quad (3)$$

We can use the formula defined in (3) to improve coding performance of intra prediction in HEVC. It is performed in a block with a recursive way by combing directional intra prediction and the Markov process. As we know, weighted parameters are vital for coding performance. Different prediction mode makes correlation between the current pixel and neighboring two pixels different, which is reflected on weighted parameters. So a mode dependent method is needed to accomplish the combination between directional intra prediction and the Markov process.

3.2. Mode dependent intra smoothing filter

In this section, we introduce the details of the proposed method. The main idea is to implement formula (3) by using different weighted parameters for different intra prediction modes. At first, we divide 35 intra prediction modes (33 directional modes, DC, and Planar) into three mode groups based on directions. Group 1 consists of modes with numbers from 22 to 34, and Group 2 consists of modes with numbers from 2 to 14, and the others belong to group 3. We design three different 3-tap filters for different mode groups respectively. The mapping between prediction modes and filters is shown in TABLE I.

TABLE I. Mapping between prediction modes and filters

Group	1	2	3
Mode	[22, 34]	[2, 14]	others
Filter	*f*1	*f*2	*f*3

Group 1 only contains 13 vertical primarily prediction modes, which mainly utilize above boundary pixels as reference samples for directional intra prediction. So in MDISF process, weighted parameter of the left pixel is larger than that of the above pixel in the corresponding filter *f*1. The purpose is to utilize left boundary pixels as references more sufficiently. Similarly, *f*2 has larger weighted parameter of the above pixel than the left pixel. And *f*3 has equal weighted parameter for left and above pixels. The weighted parameters must be as simple as possible, which guarantees low complexity. The precisions of proposed filters are 1/8 and 1/16, as shown in TABLE II.

TABLE II. Parameters of filters for different PU partitioning

Filter	Partitioning	α	β	δ
*f*1	2Nx2N	3	1	4
	NxN	5	2	9
*f*2	2Nx2N	1	3	4
	NxN	2	5	9
*f*3	2Nx2N	3	3	2
	NxN	3	3	10

As shown in TABLE II, there are different weighted parameters for different prediction unit (PU) partitioning. Pixels in the block are closer to reference boundary pixels with PartSize_NxN than PartSize_2Nx2N, and directional intra prediction generates more accurate prediction signals. In this case, weighted parameter of the current pixel is larger. ε is 4 or 8 to implement the smoothing filter by additions and shifts for different weighted parameters.

Besides, intra prediction in chroma component is smoother than luma component, so simple filter is applied on chroma component, which is defined in TABLE III.

TABLE III. Parameters of the filter for chroma

Filter	Partitioning	α	β	δ
*f*4	2Nx2N	1	1	2
	NxN	1	1	6

3.3. Integration in HEVC

The proposed mode dependent intra smoothing filter is integrated in HEVC to evaluate its efficiency, which is located after intra prediction of HEVC. The framework is shown in Fig. 3.

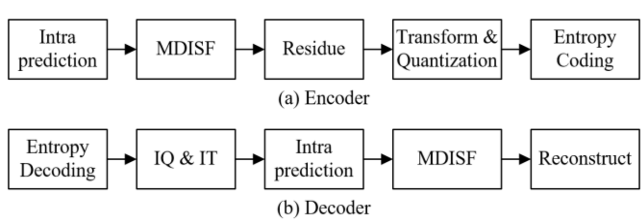


Fig. 3. Framework of combination between MDISF and directional intra prediction.

The proposed MDISF method reduces the average distortion of the block and makes prediction residue transform-friendly. It can predict blurred or weak directionality blocks well. However, it may reduce the compression efficiency if other blocks are encoded by MDISF. Thus a CU level flag is set to indicate whether MDISF is used. HEVC encoder decides whether to use MDISF by rate distortion optimization (RDO).

4. EXPERIMENTAL RESULTS

4.1. Experimental settings

In this section, experiments are carried out to verify the compression efficiency of the proposed MDISF algorithm and it is integrated into HM 16.0, which is the reference software of HEVC, and follows common test conditions defined in [15]. All intra encoder setting configuration is simulated to demonstrate its performance. Total 18 sequences with 8 bit depth and all frames are encoded in our experiments, including Class A (4Kx2K), B (1080P), C (WVGA), D (QWVGA), and E (720P). Quantization parameter (QP) used in our experiments varies among 22, 27, 32, and 37. Computer with Intel i7-4790 3.6GHz quad-core processors with 32GB memory and Microsoft Windows 7 ultimate operating system is used as the test platform. The proposed method and HM 16.0 are compiled with Microsoft Visual Studio 2013.

4.2. Coding performance

TABLE IV shows coding performance of the proposed MDISF algorithm compared to HM16.0. The average coding gain is about 1.1% (up to 1.8%) for luma component. As shown in the table, compression efficiency of all sequences are improved. Besides, the average coding gain are about 1.2% and 1.3% on average for two chroma components respectively.

The coding gains of the algorithm are different for sequences with different resolutions. For simplicity, we classify sequences into low resolution (LR) and high resolution (HR) categories. LR sequences consist of class C and D, while HR sequences consist of class A, B, and E. the coding gain of HR is about 0.8%, 0.9%, and 1.0% on average and the average gain is about 1.3%, 1.4%, and 1.6% on average. Obviously, it achieves better compression efficiency on HR than LR scenarios. This is due to in HR sequences, large prediction units (PUs) are usually chosen as best blocks to be encoded. Distance between pixels in large PU and reference boundary pixels is farther than small PU, which results more accurate prediction. And directionality in larger blocks is not obvious and strong. The proposed mode dependent intra smoothing filter algorithm reduces these problems well by reducing the average distortion.

We decide whether to use MDISF by RDO, making encoding time increase obviously. Two straightforward fast algorithms are used when calculating rate distortion cost of MDISF. Firstly, we limit the reserved candidate mode number after rough mode decision (RMD). Secondly, if there is no residue in intra prediction, our MDISF method is skipped. The encoding time of the MDISF method increases about 60% with all intra configuration compared to HM 16.0. Since directional information is reserved, it is easily to reduce complexity by using other fast algorithms.

TABLE IV. BD-rate of proposed MDISF algorithm compared to HM 16.0

Class	Sequence	Y	U	V
A	*Traffic*	-1.4%	-1.2%	-1.4%
	PeopleOnstreet	-1.8%	-1.5%	-1.7%
B	*Kimono*	-1.3%	-1.5%	-1.3%
	ParkScene	-1.4%	-1.7%	-1.6%
	Cactus	-1.4%	-1.3%	-1.8%
	BasketballDrive	-1.3%	-1.5%	-1.7%
	BQTerrace	-0.7%	-0.3%	-0.6%
C	*BasketballDrill*	-0.7%	-1.1%	-1.2%
	BQMall	-1.0%	-1.1%	-1.3%
	PartyScene	-0.6%	-0.6%	-0.7%
	RaceHorses	-1.1%	-1.2%	-1.4%
D	*BasketballPass*	-1.0%	-1.2%	-1.4%
	BQSquare	-0.3%	-0.1%	-0.2%
	BlowingBubbles	-0.7%	-0.8%	-0.9%
	RaceHorses	-1.0%	-1.2%	-1.3%
E	*FourPeople*	-1.1%	-1.4%	-1.5%
	Johny	-1.2%	-2.1%	-2.0%
	KristenAndSara	-1.1%	-2.1%	-1.9%
Avg. (LR sequences)		-0.8%	-0.9%	-1.0%
Avg. (HR sequences)		-1.3%	-1.4%	-1.6%
Avg.		-1.1%	-1.2%	-1.3%

To further analyze the coding performance, we calculate the usage rates of MDISF for different sequences with different configurations.

TABLE V shows usage rates of sequences with different CU sizes and constant QPs. The usage rate in HR sequences is a little higher than LR sequences with all CU sizes. Especially, class A has the highest usage rate of all, which is compatible with TABLE IV, in which coding gain in class A is the best. Since distance between coded pixels and boundary reference pixels in large CU is larger than that in small CU, usage rate of MDISF in large CU is higher than small CU.

TABLE V. Usage rates of MDISF in different CU sizes and constant QPs

QP	Sequences	Size of CU			
		64x64	32x32	16x16	8x8
27	HR	30%	38%	35%	29%
	LR	-	35%	33%	24%
32	HR	28%	36%	30%	23%
	LR	-	32%	27%	21%

TABLE VI shows usage rates of different QPs and constant CU sizes. The average usage rate is about 32% and it is almost same for different QPs. The MDISF method improves coding performance by reducing the average distortion of a block, which is robust to QP.

TABLE VI. Usage rates of MDISF in different QPs and constant CU sizes

Size of CU	Sequences	QP			
		22	27	32	37
32x32	HR	38%	38%	36%	32%
	LR	34%	35%	32%	28%
16x16	HR	38%	35%	30%	25%
	LR	37%	33%	27%	23%

Fig. 4 also shows the distribution of coding units (CUs) coded by the proposed MDISF algorithm in the 500th frame of sequence BasketballPass with QP equaling to 37. In Fig. 4, green CUs are coded by conventional intra prediction and blue ones are coded by the proposed MDISF algorithm. Blurred regions or weak directional regions are coded by MDISF algorithm.

Fig. 4. Distribution of CUs coded by MDISF method in the 500th frame of *BasketballPass*.

5. CONCLUSIONS

In this paper, we propose a mode dependent intra smoothing filter to improve coding performance of intra prediction, which employs the Markov model to smooth the predicted pixels. Experimental results show that the proposed method can achieve average 1.1% (up to 1.8%) BD-rate reduction for luma component compared to HM 16.0.

6. ACKNOWLEDGEMENT

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