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TR2012-035 May 2012

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Picture Coding Symposium (PCS)

Predictive Coding of Intra Prediction Modes for High Efficiency Video Coding

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***Abstract*—The High Efficiency Video Coding (HEVC) standardization process currently underway includes many tools for the coding of intra pictures. HEVC allows for many more intra prediction modes or directions as compared to previous standards. Efficient coding of these modes is therefore important because the modes consume a non-negligible portion of the total bit-stream used for coding intra pictures. In this paper, a predictive coding method is proposed to reduce the number of bits needed for signaling the intra prediction modes, where the spatial angular correlation between the intra prediction mode of the current Prediction Unit (PU) and the neighboring PUs is computed using a few modulo-N arithmetic operations that do not impact encoder or decoder run-times. The proposed method provides similar or greater improvements in compression efficiency as compared to competing tools, while requiring no changes to the existing bit-stream syntax.**

***Index Terms*—HEVC, Video Compression, Intra prediction, Entropy Coding**

I. Introduction

Recently, the High Efficiency Video Coding (HEVC) [1] activity has been launched by the Joint Collaborative Team on Video Coding (JCT-VC). One of the goals of this effort is to develop a new video coding standard that can achieve a 50% improvement in compression efficiency with a similar video quality as compared to the well-known H.264/AVC standard [2]. Although the standard being developed for the HEVC initiative is new, it still conforms to a block-based hybrid predictive coding paradigm.

In order to evaluate the the performance of coding tools introduced to HEVC, the HEVC Test Model (HM) [3] software is used. Typically, several competing methods are proposed for a similar functionality, and the best tools, accounting for both efficiency and complexity, are considered for adoption.

Many tools adopted early in the development process achieved improvements in compression efficiency of several percent. Over subsequent JCT-VC meetings, the relative gains produced by adopted tools has decreased. For the previous meeting in July 2011, many proposed tools yielded reductions in bit-rates of less than 1%. Accordingly, the complexity or amount that a proposed tool affects the bit-stream syntax is also considered.

In this paper we will focus on intra coding for HEVC, for which number of new tools have been adopted. Among those tools, one fundamental difference from H.264/AVC is the increase in the number of intra prediction modes. Up to 35 modes are available, 33 of which perform prediction along a particular angle or direction. From an entropy coding perspective, the average number of bits to encode one intra prediction mode for H.264/AVC would be $\log_2(9) \approx 3.2$; the value for HEVC is $\log_2(35) \approx 5.1$ bits. Sometimes the benefit of having extra intra prediction modes will be counteracted by the the increased overhead of intra prediction mode coding (IPMC). Experiments show that IPMC can consume about 8%$\sim$12% of the overall bit-rate for intra coded pictures, so it is worthwhile investigating tools that reduce the rate of this portion of the bit-stream. In this paper, a predictive method using modulo-N arithmetic is proposed to reduce the average number of bits used to signal the intra prediction mode, thus improving coding efficiency. This will be done in a way that does not require any changes to the existing bit-stream syntax.

The remainder of this paper is organized as follows: Section II gives an overview of related work. Section III presents a proposed method for IPMC. In Section IV, simulation results are presented and discussed. Conclusions are addressed in Section V.

II. Review of Related Work

A. Overview of intra prediction mode coding in HEVC

For intra coding, pixels within a block are predicted from adjacent reference pixels from neighboring previously-decoded blocks. One intra prediction mode is associated with each prediction block, also referred to as a Prediction Unit (PU). In Fig. 1, mode indices 0$\sim$17

†This work was done while working at MERL

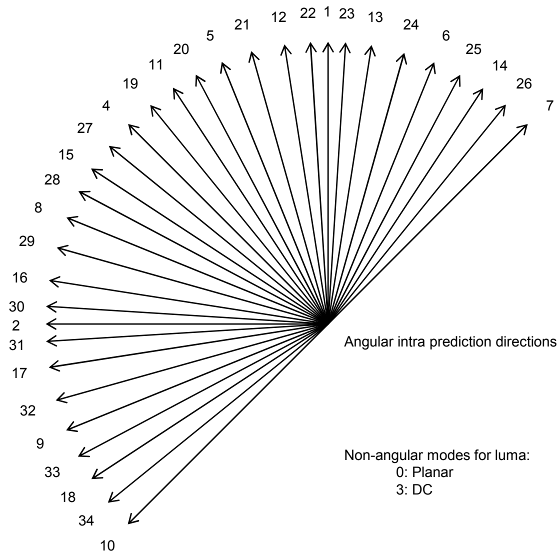

Fig. 1. Luminance intra prediction directions and their mode indices

can be used for PUs of 4×4 pixels, and modes 0∼34 are used for 8×8, 16×16 and 32×32 PUs, for luma. Modes 1, 2, and 4∼34 are angular modes in which prediction for a PU is performed along the direction specified by the mode.[1] If the angular intra prediction mode (IPM) points to a non-integer location in the reference row or column, a 2-tap filter is used to linearly interpolate its reference sample from the closest two samples. The two non-angular modes are DC and planar [4]. DC mode is the same as in H.264/AVC, and planar mode was introduced to improve the subjective quality of regions containing smooth gradients.

For the past several JCT-VC meetings, IPMC has been studied in Core Experiment 6 (CE6) [5]. In HEVC Working Draft 4 [1], the IPM is either signaled explicitly or inferred from previously decoded modes from the PUs above and to the left of the current PU. The modes from these two neighboring PUs are known as the set of Most Probable Modes (MPM). The current mode is parsed from the bit-stream as follows: A 1-bit flag **prev_intra_luma_pred_flag**, referred to here as *MPM-flag*, is signaled to indicate whether the current IPM is identical to one of the MPMs. If so, another flag is sent to indicate which of the two MPMs to use for the current mode. When a neighboring block is not available, then typically DC or planar modes are used to populate the MPM set.

If *MPM-flag* is false, then the current mode is explicitly signaled after using a table to map it to a variable-length codeword, or it is mapped to a fixed-length codeword, depending upon the codec's configuration. The table is designed in such a way that entries near the top of the table are assigned shorter codewords. When *MPM-flag* is false and the current IPM is explicitly signaled, then its position in the codeword-mapping table is swapped with the entry just ahead of it. By doing this, IPMs that occur more frequently move toward the top of the table to be associated with shorter codewords. For configurations that use fixed-length codewords, the IPM is signaled using 5 or 6 bits.

[1] More recent versions of HEVC use a different numbering scheme.

Because the ranking table is updated over the whole picture, it exploits some of the global statistics over the PUs. However, there are still opportunities for achieving additional compression efficiency when coding the IPMs. Next, we will review some of these methods.

B. Improvements based on ranking tables

A direct improvement over the original approach is proposed in [6]. The key points are: 1) The ranking table is updated for every PU, based on the current IPM, even if *MPM-flag* is true. Therefore, the ordering of IPMs in the table will more accurately reflect the actual mode distribution. 2) The ranking table is used for all codec configurations, thus eliminating the fixed-length method for coding the IPM. 3) Initialization of the ranking table is simplified.

C. Differential coding of IPM

In the approach outlined in [7], the edge information of pixels in the neighboring PUs is examined to predict the angle of the current IPM. Two rows of reference pixels from the PU above and two columns from the PU to the left are required. Filters are used to calculate the gradients inside the area. The ratio σ/ρ is computed from (1), where S is the reference area and (x_i, y_i) are the two components of the gradient.

$$\sigma = 2\sum_{i\in S} x_i y_i, \rho = \sum_{i\in S} x_i^2 - y_i^2 \tag{1}$$

Together with the ratio, the signs of σ and ρ are passed to a look-up table to determine an index corresponding to the dominant edge direction. This index in turn is used to compute the current IPM. An angular IPM is indexed in both directions starting from the mode closest to the dominant direction. Hence, the IPM is differentially coded. In [7], other techniques including more complex 4-tap filters for reference sample generation and bi-directional prediction are also proposed. In Section IV, we will focus on the results that are most relevant to the differential coding concept.

III. The Proposed Method

A. Unified model and statistics for angular IPMs

Inspired by the usage of *MPM-flag*, the correlation between the current IPM (M_{curr}) and the modes from neighboring PUs (M_{left} and M_{above}) is worth exploring. To determine the angular difference between two IPMs,

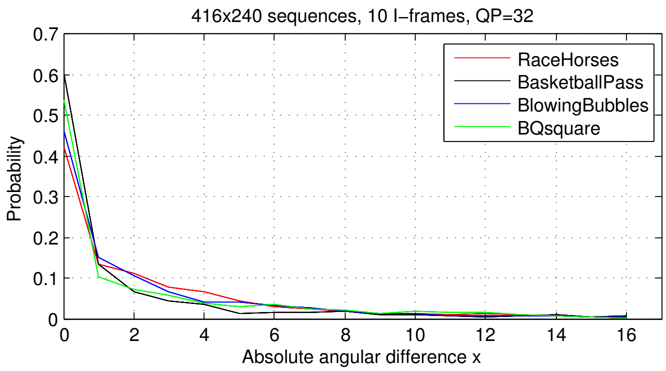

Fig. 2. Probability distribution of angular difference

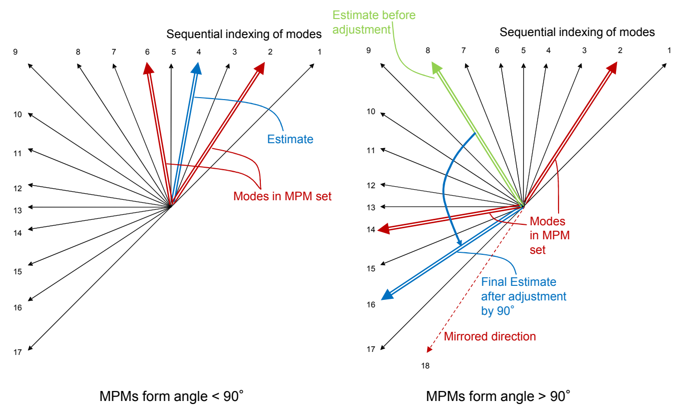

Fig. 3. Generation of predictor for the current intra prediction mode

we first map the mode indices shown in Fig. 1 to sequential indices, counterclockwise starting with 1. For example, mode $M_{left} = 25$ is mapped to $M'_{left} = 4$. The angular difference can then be represented as a difference between mapped indices. We would like to see whether the modes in the MPM set are good predictors for the current mode. For a subset of sequences used in Section IV, Fig. 2 shows the distribution of angular differences between the current mode M_{curr} and the closer of the two MPMs $\{M_{left}, M_{above}\}$. The horizontal axis x is defined using the mapped modes as follows:

$$x = \min\{\left|M'_{curr} - M'_{left}\right|, \left|M'_{curr} - M'_{above}\right|\}. \quad (2)$$

If the difference between the mapped current mode and either of the mapped MPMs is zero, then the current mode is contained in the MPM set.

This plot confirms that small angular differences between the current mode and the MPM set occur most frequently, and the frequency decreases as the angular difference becomes larger. The zero difference occurs with the highest probability (around 0.5), which also justifies the one bit used for *MPM-flag*.

B. The proposed method for IPMC in HEVC

Based on the above analysis, we present a method for coding the current mode when it is not already in the MPM set. Based on the number of available angular modes in the MPM set, three cases are considered:

1) *Two different angular IPMs:* The median between the MPM indices are used as a predictor for the current mode. When mapped to sequential indices, this median is equivalent to the mean. When $M'_{above} > M'_{left}$, the difference between the mean and the mapped current mode

$$\Delta_{mode} = \frac{M'_{above} - M'_{left}}{2} - M'_{curr} \quad (3)$$

is then mapped to a codeword for signaling in the bit-stream. If $M'_{above} < M'_{left}$, then the two MPMs can be swapped before computing the predictor.

2) *One unique angular IPM:* Since we know the current mode is not in the MPM set, we set the predictor to be a mode adjacent to the angular mode in the MPM set. For example, the difference to be signaled can be $\Delta_{mode} = \left(M'_{left} - 1\right) - M'_{curr}$.

3) *No angular IPMs:* The current IPM will be signaled without any prediction or mapping.

Fig. 3 shows two examples for case 1. Given N total possible IPMs, if $|M'_{above} - M'_{left}| < \frac{N}{2}$ then the angle between the two MPMs is less than 90°. The predictor will therefore be aligned in the same general direction as the MPMs. If, however, the difference between the MPMs exceeds $\frac{N}{2}$, then the predictor will be generally aligned in a direction orthogonal to both MPMs. In the pictured example, the mapped MPM set is $\{2, 14\}$, and the predictor is 8, which is inconsistent with the idea that if both MPMs are aligned with features in the PU, then the predictor is likely to be similarly aligned. In this case, we mirror one of the MPMs to point in the opposite direction, noting that it still lies along the same line formed by the original direction. The median between the mirrored MPM and the other MPM then becomes the predictor. As shown in Fig. 3, instead of actually performing the mirror and recomputing of a median, we can rotate the existing median 90° by adding $\frac{N}{2}$. The difference to be signaled becomes

$$\Delta_{mode} = \frac{M'_{above} - M'_{left}}{2} + \frac{N}{2} - M'_{curr}. \quad (4)$$

If any of the calculated predictors produce a sequential mode index that is outside the valid range of available IPMs, then it can be mirrored by adding or subtracting $N - 1$, so that it lies along the same line. This circular or modulo-N representation of prediction directions simplifies calculation of the prediction mode difference.

Once the difference is computed, it is mapped to a codeword. When the current IPM is non-angular (DC or planar), we reserve a predefined symbol for it. To make the codeword mapping for both angular and non-angular modes unique, it needs to be adjusted such that each symbol is can be mapped to just one IPM. For example, if the symbol “3” is used to represent DC/planar mode, then 1 is added to any adjusted prediction mode differ-

TABLE I
EXAMPLE OF CODEWORD ASSIGNMENT FOR IPM RESIDUES

Mode Res.	DC/planar	0	1	-1	2
Symbol	0	1	2	3	4
Length	3	3	3	3	4
Codeword	000	001	010	011	1000
Mode Res.	-2	3	-3	4	...
Symbol	5	6	7	8	...
Length	4	4	4	5	...
Codeword	1001	1010	1011	11000	...

ences ≥ 3. Because the DC and planar modes occur quite frequently, we assign the first symbol in the codeword table to represent DC/planar, and then signal a 1-bit flag to differentiate between them.

The fundamental difference between this method and the one specified in the Working Draft is that the Working Draft signals the mode explicitly, and we signal a difference value. Our method therefore requires no change to the PU bit-stream syntax. Only the computations on the decoded parsed values are changed.

Table I shows an example mapping from the prediction mode difference to a symbol and its associated codeword. Smaller differences are associated with shorter length codewords. Compared to [6], this table does not need to be adaptive. The spatial correlation among neighboring IPMs allows us to adapt to local changes in video content.

IV. Simulation Results and Discussion

A. Simulation setup

We implemented the proposed algorithm in the HM3.3 reference software, using the All-Intra High Efficiency (AI-HE) test conditions from [8]. A total of 20 sequences having resolutions ranging from 416×240 to 2560×1600 are coded. High Efficiency (HE) and Low Complexity (LC) configurations are tested. For each configuration, QP values $\{22,27,32,37\}$ are tested using the unmodified HM3.3 codec as a reference for the BD-Rate metric. Results from [6] and [7] are also listed for comparison. We obtained comparable results in [9] using HM4.0.

B. Results and discussion

From Table II, it can be seen that the proposed method slightly outperforms JCTVC-F269, and it has a negligible impact on encoder and decoder run times. If we examine these algorithms in detail, the ranking table and its updating process are not needed in the proposed method. The mapping from the adjusted prediction mode difference to a codeword is fixed. JCTVC-F566 achieves similar performance gain as the proposed method but the run-time increase is significant. Adding a 4-tap filter to JCTVC-F566 will result in a further 0.4%/0.5% (for HE/LC) BD rate reduction, but with an additional increase in complexity. Compared with the other two methods, the proposed one achieves a good balance between performance and complexity, without requiring any change to the PU bit-stream syntax.

TABLE II
SIMULATION RESULTS VS. HM3.X ANCHOR (POSITIVE BD-RATE REDUCTIONS INDICATE IMPROVEMENT)

Algorithm		F269 [6]		F566 [7]		Proposed	
Configuration		HE	LC	HE	LC	HE	LC
BD Rate Reduction (%)	Cla. A	0.3	0.1	0.2	0.2	0.3	0.1
	Cla. B	0.4	0.1	0.3	-0.1	0.3	0.2
	Cla. C	0.3	0.1	0.6	0.5	0.3	0.2
	Cla. D	0.2	0.1	0.3	0.0	0.3	0.3
	Cla. E	0.2	0.1	0.4	-0.1	0.6	0.3
BD Average (%)		0.3	0.1	0.4	0.1	0.4	0.2
Enc. Runtime (%)		100	100	111	121	101	100
Dec. Runtime (%)		101	101	103	105	100	99

V. Conclusions

A new method for coding intra prediction modes is discussed in this paper. A circular representation of modes is used, and the angular difference between the current mode and a prediction based on previously-decoded neighboring modes is coded. Compared to the existing methods, the need for a ranking table and its updating process is eliminated, without requiring any changes to the current bit-stream syntax specifications. The proposed method provides a reasonable improvement in compression efficiency, while requiring only a few modulo-N arithmetic operations to process prediction mode values.

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