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► **To cite this version:**

Dayong Wang, Yu Sun, Weisheng Li, Ce Zhu, Frédéric Dufaux. FAST INTER MODE PREDICTIONS FOR SHVC. IEEE International Conference on Multimedia & Expo (ICME'2019), Jul 2019, Shanghai, China. pp.1696-1701, 10.1109/ICME.2019.00292 . hal-02063056

HAL Id: hal-02063056

<https://hal.science/hal-02063056>

Submitted on 10 Jan 2020

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FAST INTER MODE PREDICTIONS FOR SHVC

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ABSTRACT

The Scalable High Efficiency Video Coding (SHVC) has very high coding efficiency, but its computational complexity is also very high. This definitely limits its wide applications, particularly for real-time video applications. Therefore, it is crucial to improve the coding speed. In this research, we have proposed a new inter mode prediction algorithm for quality SHVC, in order to improve the coding speed while maintaining coding efficiency. First, we divide mode prediction into square mode prediction and non-square mode prediction. Second, in the square mode prediction, Inter-Layer Reference (ILR) and merge modes are predicted based on depth correlation. Moreover, ILR mode, merge mode and inter 2Nx2N are early terminated based on Rate Distortion (RD) cost. Third, if the early termination condition cannot be satisfied, non-square modes are further predicted based on the distribution of residual coefficients. Experimental results have demonstrated that the proposed algorithm can significantly improve the coding speed with negligible coding efficiency loss.

Index Terms— SHVC, inter mode, square mode, non-square mode, early termination

This work was supported in part by the Natural Science Foundation of China under Grant 61401247, U1713213, 61472055, 61571102 and 61571070, in part by Chongqing science and Technology Commission Project under Grant cstc2015jcyjBX0009, cstc2016jcyjA0543, cstc2017jcyjAX0142, cstc2018jcyjAX0525 and cstc2018jcyjAX0225, in part by the Key Project of Sichuan Provincial Department of Science and Technology under Grant 2018JY0035, in part by Ministry of Education - China Mobile Research Fund Project under Grant MCM20170203, in part by faculty sabbatical leave fund from Uni. of Central Arkansas.

1. INTRODUCTION

With the rapid development of science and technology, video applications have been widely used in our daily life. Various video applications, such as digital TV broadcasting, video conferencing, wireless video streaming, and smart phone communications, have become ubiquitous. Different applications may use various devices, and users may also use various devices even for the same application. These devices may have different screen resolutions, processing capabilities, and network bandwidth requirements. In addition, different networks, such as broadband networks and wireless networks, may have different characteristics. Even in the same network, network bandwidth may also vary in different conditions. This requires that video streaming can adapt to different devices and network bandwidths. Scalable Video Coding (SVC), an extension of H.264/AVC, can efficiently solve these problems [1]. In order to provide scalability, SVC consists of a base layer (BL) and one or more enhancement layers (ELs). A SVC stream may support temporal, spatial and quality scalability, or a combination thereof. Scalability in temporal, spatial and quality refer to frame rate from low to high, spatial resolution from low to high and SNR from low to high, respectively. In recent years, the newest video coding standard, namely HEVC, has been developed. Since HEVC uses more advanced features and higher efficiency coding tools, it has better coding efficiency than previous video coding standards. HEVC only uses about half bit rates in comparison with H.264/AVC, while maintaining the same video quality level [2]. Since HEVC has very high coding efficiency, it attracts extensive attentions and several significant improvements have been further made on top of HEVC [3–5]. In order to accommodate heterogeneous device capabilities, network conditions and client applications, Scalable High Efficiency

Video Coding (SHVC), an extension of HEVC, has been proposed. Similar to SVC, SHVC also supports scalability in temporal, spatial, quality. In addition, it also provides bit-depth scalability (bit depth from low to high, e.g., 8 to 10 bit), and color gamut scalability (color gamut from narrow to wide, e.g., ITU-R Recommendation BT.709 to BT.2020) [6].

Although HEVC has very high coding efficiency, its coding complexity is also very high, with an increase by about two to four times when compared to H.264/AVC [2]. In SHVC, multiple layers need to be encoded, using inter-layer predictions. Further, the encoding process of each layer is the same as that of HEVC. Thus, the coding process of SHVC is even more complex than that of HEVC. Therefore, it is highly desired to improve the coding speed, especially for wireless and realtime applications.

In order to improve the coding speed, we propose a new scheme for partition prediction to accelerate the coding of Inter prediction for quality SHVC (QS). The novelties and the contributions of the proposed algorithm are summarized below: (1) Inter-layer Reference (ILR) mode and merge mode are predicted based on depth correlation; (2) Square partitions, including ILR mode, merge mode and inter2Nx2N, are early terminated based on their RD-cost relationships; (3) Non-square partitions are predicted based on the distribution of the residual coefficients of square partitions.

2. RELATED WORK

To reduce the coding complexity of HEVC, several methods have been proposed in [7, 8]. Pan et al. [7] uses the mode of depth correlation, AZB, and the motion estimation information to early detect merge mode. The research in [8] predicts candidate depths based on the previous frame and neighboring CUs, and then early terminate unnecessary CUs according to motion homogeneity checking, RD cost checking and SKIP mode checking.

Some research focus on improving the coding speed of SHVC. The research in [9] uses spatial and inter-layer correlations to propose a probabilistic approach to predict the quad-tree structure of coding tree units (CTUs) for quality and spatial scalable SHVC. Tohidypour et al. use coding information of relative CUs including neighboring CU in EL and the co-located CU in BL to build a probabilistic model, and then uses the proposed probabilistic model to predict the candidate modes of the current CU in the EL to improve the coding speed [10]. Wang et al. [11] predict candidate depths. In each candidate depth, if ILR mode early termination condition is satisfied, intra mode prediction can be skipped; otherwise intra mode prediction needs to be checked. Afterwards, if depth early termination is satisfied, other depths can be directly skipped to improve the coding speed.

Since both SHVC and HEVC use the same advanced coding tools, the complexity reduction algorithms developed for HEVC can also be utilized for SHVC. But these algorithms

Table 1. The Proportions of modes in square partition

Sequence	ILR& Merg	Inter2Nx2N	Intra2Nx2N
Sunflower	83.4%	15.4%	1.2%
Tractor	86.1%	12.9%	1.0%
Flower vase	79.0%	19.9%	1.1%
PartyScene	84.5%	14.2%	1.3%
BlowingBubbles	82.9%	16.5%	0.6%
RaceHorses	81.1%	17.5%	1.4%
Park	87.5%	12.1%	0.4%
Town	88.1%	11.6%	0.3%
Average	84.1%	15.0%	0.9%

developed for HEVC do not exploit inter-layer correlation, so they cannot effectively improve SHVC's coding speed. In addition, the algorithms developed for SHVC use the same way to predict all candidate partitions and modes. However, since different partitions and modes have different features, using the same method is not always efficient. Therefore, in this research, we propose a fast mode prediction for quality SHVC.

3. PROPOSED FAST PARTITION AND MODE DECISION

In every coding depth of SHVC, a CU is predicted by square partition and non-square partition. Square partition includes ILR mode, merge mode and Inter2Nx2N and Intra2Nx2N mode. Non-square partition includes 2NxN, Nx2N, 2NxN_U, 2NxN_D, nLx2N and nRx2N. As NxN is only used when depth is 3, we have not considered this mode for the sake of simplicity. More specifically, we have developed two methods to improve the coding speed for square partition and non-square partition, respectively.

3.1. Square partition mode prediction

To improve the coding speed, for square partition, we have conducted experiments to obtain the proportions of the four modes (ILR mode, merge mode, Inter2Nx2N mode, Intra2Nx2N mode). To meet the different resolution requirements, two sequences in each class B, C, D and E are selected in our experiments. More specifically, the following test sequences are used: Sunflower and Tractor in class B; Flower vase and PartyScene in class C; BlowingBubbles and RaceHorses in class D; and Parkrunner and Town in class E. As suggested in common SHM test conditions (CSTC) [12], each test sequence is encoded under the Random Access (RA) main configuration. The QPs used for the BL are (26, 30, 34, 38), and the corresponding QPs used for the EL are (22, 26, 30, 34). Based on these experiments, the proportions of modes in square partition are listed in Table 1.

From Table 1, we can observe that: (1) ILR and merge modes have the highest probability; (2) Inter2Nx2N has a

Table 2. The depth correlation degree of ILR and merge modes

Sequence	depth correlation degree
Sunflower	98.1%
Tractor	95.4%
Flowervase	97.8%
PartyScene	94.7%
BlowingBubbles	95.4%
RaceHorses	92.3%
Park	96.0%
Town	98.5%
Average	96.0%

smaller but non-negligible; (3) Intra2Nx2N has a very small probability. Therefore, ILR and merge modes always need to be checked, and Intra2Nx2N can be skipped directly. Regarding Inter2Nx2N, if the mode is always checked, much unnecessary time would be spent. Conversely, if the mode is skipped directly, the coding efficiency would be obviously degraded. Therefore, we first check ILR and merge modes, and decide whether they are the best modes. In the affirmative, we can only select these modes and skip Inter2Nx2N mode. Otherwise, we still need to check Inter2Nx2N mode and compare the difference of RD costs between ILR and merge modes and Inter2Nx2N mode. If the difference is not significant, square partition can be regarded as the best mode and non-square partition modes can be skipped directly. Otherwise, non-square partition modes need to be further checked. Base on the above analysis, in this paper, we develop ILR and merge modes prediction and square partition mode early termination. The details are listed below.

3.1.1. ILR and merge modes prediction

Since the depth is strongly correlated, the parent CU and its children CUs may use similar modes. In order to investigate the depth correlation degree between parent CU and its children CUs in ILR and merge modes, we have conducted experiments using the same condition mentioned above. Based on these experiments, the depth correlation degree of ILR and merge modes are listed in Table 2.

In Table 2, depth correlation degree refers to the probability that children CUs select ILR and merge modes given parent CU using ILR and merge modes. From Table 2, we can find that the average depth correlation degree is 96%. This means that when a parent CU uses ILR and merge modes, its children CUs basically also use ILR and merge modes. Therefore, when a parent CU uses ILR and merge modes, its children CUs can only check ILR and merge modes.

3.1.2. Square partition mode early termination

When the parent CU of the current CU does not use ILR and merge modes, Inter2Nx2N needs to be checked. As mentioned above, when all modes of square partition have been checked, if their RD cost difference is not significant, we only need to check square partition modes and skip non-square partition directly. In order to determine whether they have a significant difference, we can compare their quantized residual coefficients. If the differences of their quantized residual coefficients between ILR & merge modes, and Inter2Nx2N mode are very small, that means that their RD costs are not significantly different [?]. Since every CU is composed of multiple 4x4 blocks, we calculate quantized residual coefficients in 4x4 block and derive the decision as follows.

For a DCT coefficient w , its quantized value z is:

$$z = w/Q_{step} + 1/6, \quad (1)$$

where Q_{step} is quantization step. As we know, if the condition $|(w_1 - w_2)/Q_{step}| \leq 1$ is met, no information needs to be coded. Thus, we can regard that they are no significant difference. As a result, we can derive:

$$|w_1 - w_2| \leq Q_{step}, \quad (2)$$

where w_1 is the residual coefficients of ILR and merge modes, and w_2 is residual coefficients of Inter2Nx2N mode.

In SHVC, DCT coefficient w of 4x4 blocks is computed as:

$$w = \sum_{u=0}^3 \sum_{v=0}^3 h_{iu} x_{uv} h_{jv} / (128 \times 128), \quad (3)$$

Combing (2) and (3), we can derive:

$$\begin{aligned} |w_1 - w_2| &\leq \sum_{u=0}^3 \sum_{v=0}^3 |h_{iu} (x_{uv}^1 - x_{uv}^2) h_{jv}| / (128 \times 128) \\ &= \sum_{u=0}^3 \sum_{v=0}^3 |h_{iu} h_{jv}| |x_{uv}^1 - x_{uv}^2| / (128 \times 128) \end{aligned}, \quad (4)$$

where h_{iu} refers to the value in the integer DCT transform matrix at the (i, u) position in SHVC, and x_{uv} refers to the residual value in the residual matrix at the (u, v) position. Since the maximum value of $|h_{iu}|$ is 83, combing (2) and (4), we can obtain:

$$\sum_{u=0}^3 \sum_{v=0}^3 |x_{uv}^1 - x_{uv}^2| \leq 2.5Q_{step} \quad (5)$$

From (5), we can derive:

$$\sum_{u=0}^3 \sum_{v=0}^3 |x_{uv}^1| - \sum_{u=0}^3 \sum_{v=0}^3 |x_{uv}^2| \leq 2.5Q_{step} \quad (6)$$

Sum of Absolute Difference (SAD) of two 4x4 blocks is obtained by (6) and can be written as:

$$|SAD_1 - SAD_2| \leq 2.5Q_{step} \quad (7)$$

Since only depth 0, 1 and 2, namely 64x64, 32x32, 16x16 CU, have non-square partition, we can derive:

$$|SAD_1 - SAD_2| \leq 40mQ_{step}, \quad (8)$$

According to CU size, m is set 16, 4, 1, corresponding to 64x64, 32x32, 16x16 CU, respectively.

Since SAD costs have strong relationship with RD costs, for convenience purposes, we have replaced SAD costs with RD costs, (8) can be written as:

$$|RD_1 - RD_2| \leq 40mQ_{step} \quad (9)$$

If the above condition is met, we can only select square partition modes and skip non-square partition modes directly. Otherwise, we still need to check non-square partition modes.

3.2. Non-square partition mode prediction

Non-square partition mode includes inter2NxN, interNx2N, inter2NxN, inter2NxN, interNx2N, inter2NxN, inter2NxN, interNx2N, as shown in Fig.1.

In general, if the prediction is efficient, residual coefficients will obey a certain distribution. Therefore, we can also predict the best partition by studying the distribution of residual coefficients. Residual coefficients are typically modeled using a Gaussian distribution [13] or a Laplacian distribution [14]. The Gaussian distribution is selected due to its superior performance in our experiments. Suppose residual coefficients of a CU obey a Gaussian distribution, we can divide a CU into two parts and decide whether they have significant difference to select the corresponding partition mode. Hypothesis testing is used to determine if the two parts for each division present a significant difference. For this purpose, t-test is used, which is the test statistics to investigate the significance of the difference between two sampled expected values. The expected values of the CU residual coefficients can be calculated by:

$$\bar{X}_1 = \frac{\sum_{i=1}^M \sum_{j=1}^N r_{ij}}{M \times N}, \quad (10)$$

where M and N respectively are the width and height of the partitioned CU, r_{ij} is the residual coefficient value in (i, j) . CUs can take three sizes, 64x64, 32x32 and 16x16. According to the knowledge of mathematical statistics, if residual coefficients of a CU, obeying a Gaussian distribution, are divided into two parts. These two parts will also obey a Gaussian distribution. Suppose that the residual coefficients of two parts in each division can be respectively modeled as:

$$X_1 \sim N(\mu_1, \sigma_1^2), X_2 \sim N(\mu_2, \sigma_2^2), \quad (11)$$

where X_1 is a Gaussian distribution of one part, X_2 is a Gaussian distribution of the other part in a division, μ and σ^2 are their expected value and variances.

The test statistics t can be computed as:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)}{S_w \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}, \quad (12)$$

where $S_w^2 = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}$, S_1^2 and S_2^2 are the two parts' variances respectively. Assuming $\mu_1 = \mu_2$, the condition can be expressed as:

$$\frac{|(\bar{X}_1 - \bar{X}_2) - (\mu_1 - \mu_2)|}{S_w \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \leq t_{\alpha/2}(n_1 + n_2 - 1), \quad (13)$$

where n_1 and n_2 are the numbers of residual coefficients of the two parts in each subdivision, and α is the significance level value. Given α , the corresponding threshold $t_{\alpha/2}(n_1+n_2-1)$ is determined by T distribution table. Since there are six non-square modes shown in Fig.1, if each mode selects its own threshold, threshold values would be very complex. In order to simplify threshold values, we use the unified value. If the condition is satisfied, we can assume that there is no significant difference, and we do not need to check the corresponding modes. For example, in Fig.1.(a), if top and bottom parts have a significant difference, then inter2NxN needs to be selected. Similarly, in Fig.1.(b), if the left and right parts have a significant difference, then interNx2N need to be selected. The other modes are selected in the same way.

The optimal α and $t_{\alpha/2}(n_1 + n_2 - 1)$ can be obtained through experiments. We have performed experiments using the same condition above. Commonly used values for α , 0.5, 0.4, 0.3, 0.2, 0.1, 0.05, 0.02, 0.01 and 0.005, and the corresponding threshold values, 0.674, 0.842, 1.036, 1.282, 1.645, 1.96, 2.326, 2.576 and 2.807, are tested. Table 3 shows the corresponding coding efficiencies, which are measured by BDBR under different sequences and thresholds. BDBR represents the bitrate difference at an equal PSNR [15]. A negative BDBR represents an increase in coding efficiency when compared with the reference software. From Table 3 we can observe that as the threshold value increases, the loss of coding efficiency basically increases. However, the increase is very slow, and the loss of coding efficiencies under all thresholds is very small. Obviously, the higher the threshold is, the greater the coding speed improves. Therefore, the highest threshold value, 2.807, is selected.

4. EXPERIMENTAL RESULT

The proposed fast inter prediction algorithm for QS has been implemented in the SHVC reference software (SHM 11.0) on

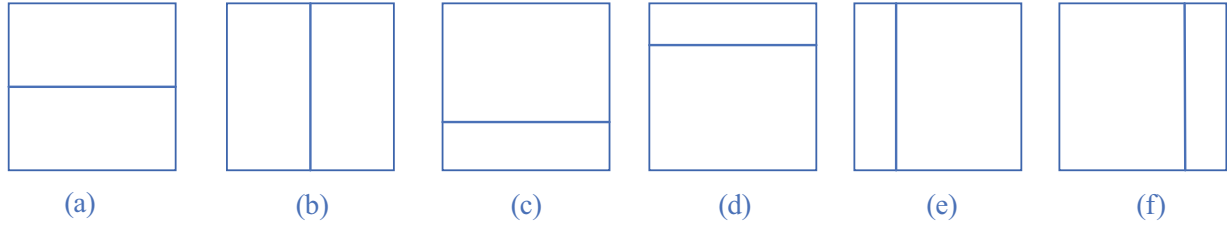


Fig. 1. Non-square partition.

Table 3. Coding efficiencies under different threshold values

Threshold	0.674	0.842	1.036	1.282	1.645	1.96	2.326	2.576	2.807
Sunflower	0.1	-0.1	-0.1	0	-0.1	0.1	0.2	0.1	0
Tractor	0	0	0	0	0.1	0.1	0.1	0.1	0.1
FlowerVase	0.1	0.1	0.2	0.3	0.3	0.4	0.3	0.4	0.2
PartyScene	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BlowingBubbles	0.1	0.1	0	0.2	0.2	0.2	0.2	0.2	0.2
RaceHorses	0	0	0	0	0.1	0	0	0	0
Park	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Town	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.4
Average	0.075	0.063	0.075	0.13	0.14	0.163	0.175	0.163	0.138

a server with Intel (R) 2.0 GHz CPU and 30 GB memory. The experimental parameters are set according to the CSTC [12]. The proposed algorithm is developed for RA coding structure. The QPs in the BL are (26, 30, 34, 38), and the corresponding QPs used for the EL are set to be (22, 26, 30, 34) and (20, 24, 28, 32), respectively. Since the eight training sequences are no longer used in our overall performance testing, our proposed algorithm is generic and effective for different types of video contents. Coding efficiency is measured by BDBR, and coding speed is evaluated by coding time in the EL. TS represents the percentage of coding time savings in the EL. In order to further demonstrate the performance of our proposed algorithm, we have compared it with EMD algorithm proposed in [7]. Two settings of QPs: Q1= (22, 26, 30, 34) and Q2= (20, 24, 28, 32) are used. Their performance comparisons in terms of coding efficiency and coding speed are shown in Table 4 and Table 5, with Q1 and Q2, respectively.

From Table 4, we can find that the average BDBR and TS of the proposed algorithm are 1.09% and 60.56%, respectively, while the average BDBR and TS of EMD are 1.55% and 55.01%. In Table 5, the coding efficiency (BDBR) of both our algorithm and EMD are degraded when compared to BDBR in Table 4. This is because that, the QP difference between BL and EL in Table 5 is 6, which is larger than the QP difference 4 used in Table 4. The larger QP difference causes the weaker inter-layer correlation. In addition, since QPs of EL in Table 5 are smaller than those in Table 4, more

Table 4. Performance comparison of the different methods

Sequence	Proposed		EMD [7]	
	BDBR	TS	BDBR	TS
Traffic	1.0%	61.06%	1.33%	64.65%
PeopleOnStreet	0.90%	60.64%	0.45%	42.81%
BasketballDrive	0.50%	60.43%	2.26%	54.23%
BQTerrace	1.10%	61.15%	2.37%	53.98%
Cactus	0.90%	60.14%	1.07%	55.36%
Kimono	1.30%	59.71%	0.98%	51.88%
ParkScene	1.90%	60.76%	2.38%	64.65%
Average	1.09%	60.56%	1.55%	55.01%

CUs may use non-square modes and the accuracy of ILR and merge modes prediction may degrade to some extent. Therefore, coding efficiency is degraded in Table 5. From Table 5, we can find that our algorithm's average BDBR and TS are 1.9% and 59.41%, respectively, while EMD's average BDBR and TS are 2.03% and 52.99%. Therefore, our proposed algorithm outperforms EMD in terms of both coding efficiency and coding speed.

5. CONCLUSION

In this paper, we have proposed a novel and effective inter mode prediction algorithm for Quality SHVC. The proposed algorithm can be further improved by combining with fast

Table 5. Performance comparison of the different methods

Sequence	Proposed		EMD [7]	
	BDBR	TS	BDBR	TS
Traffic	2.20%	58.89%	1.82%	62.34%
PeopleOnStreet	2.10%	58.95%	1.03%	40.16%
BasketballDrive	2.00%	59.42%	2.84%	51.27%
BQTerrace	1.80%	61.18%	2.93%	52.49%
Cactus	1.80%	59.25%	1.55%	52.79%
Kimono	1.30%	59.01%	1.53%	50.01%
ParkScene	1.80%	59.21%	2.52%	61.87%
Average	1.90%	59.41%	2.03%	52.99%

motion estimation methods like that in [16]. Our future work includes depth prediction to further improve the coding speed of inter prediction for quality SHVC and video communication [17].

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