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ABSTRACT

To seamlessly adapt to time-varying network bandwidths, Quality Scalable High-Efficiency Video Coding (QSHVC) is developed. However, its coding process is overwhelmingly complex, and this seriously limits its wide applications in realtime environments. Therefore, it is of great significance to study fast coding algorithms for QSHVC. In this paper, we propose a novel probability-based All-Zero Block (AZB) early termination algorithm for QSHVC. We observe that the generated residual coefficients follow the Laplace distribution if a CU is accurately predicted. Based on this observation, we derive the sum of squared differences-based AZB decision condition. Second, the probability of each coding mode and coding depth being chosen as the best ones are combined with AZBs to derive the probability-based early termination condition. The experimental results show that the proposed algorithm can improve the average coding speed by 74.95% with a 0.26% increase in BDBR.

***Index Terms*—** SHVC, probability, AII-Zero Block

1. INTRODUCTION

The popularization of smartphones underpins the growing demand for video applications. There was a significant increase in the use of videoconferencing during the Covid-19 pandemic crisis. Heterogeneous networks with time-varying channel bandwidths are used in visual communication, and bandwidth fluctuates even when working in the same network environment. This requires video streams to be scalable to a variety of network bandwidths. Quality Scalable High-Efficiency Video Coding (QSHVC) is developed to effectively address this need [1].

QSHVC is one of the scalable versions of the High Efficiency Video Coding (HEVC) standard. To achieve scalable quality, SHVC uses a Base Layer (BL) and one or more Enhancement Layers (ELs) to encode the same video sequence. Each layer is encoded with a different Quantization Parameter (QP) to achieve several video representations with different picture quality [2]. The identical encoding process as in HEVC is applied to BL, and the additional Inter-layer prediction is employed to encode ELs, where the Inter-Layer Reference (ILR) modes are introduced. Given the considerable complexity of the HEVC encoding process, the computational complexity of QSHVC is even much greater than that of HEVC. This seriously prevents the extensive deployment of QSHVC in real-time scenarios. It is therefore of great significance to develop fast coding algorithms for QSHVC.

This paper proposes a novel probability-based zero-block early termination algorithm to alleviate the computational complexity of the QSHVC encoder. We first obtain the Sum of Squared Differences (SSD)-based All-Zero Block (AZB) decision condition, which is combined with the probabilities of various modes and depths being chosen as the best ones, to derive the corresponding early termination conditions for individual modes and depths, thus terminating the evaluations

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2. RELATED WORK

To speed up the encoding process, it is straightforward to early terminate the evaluation of coding modes and depths. The Rate-Distortion (RD) cost and residual coefficients are often considered to determine whether coding modes and depths can be early terminated.

(1) RD costs-based early termination

Generally, a CU that generates a large RD cost is likely to be subdivided to a great coding depth, and vice versa. In [3], if the sum of the estimated RD cost of the sub-CUs in the current CU is larger than the RD cost of the current CU, the subdivision for the current CU is terminated. Cho et al. [4] used a Bayes decision rule to evaluate the probability of early termination for the current coding depth according to the RD cost, thus achieving fast CU splitting and pruning. To achieve an early termination for coding mode evaluation, Wang et al. [5] proposed a few conditions based on the RD cost differences among square coding modes. Wang et al. [6–8] first investigated the RD cost distributions of ILR mode and Intra mode, and then used the distributions to determine whether ILR mode is the best mode thus skipping Intra mode.

(2) Residual Coefficients-based Early Termination

To effectively exploit residual coefficients in early termination algorithms, research tends to focus on the distribution of residual coefficients, as well as AZB.

Distribution of residual coefficients: In [9], a given CU comprising residual coefficients is divided into two parts with two structures: the top half and the bottom half, and the left side and the right side. The differences in variances between the two parts in both structures are calculated, respectively. If either of the differences is significant, the CU is divided further, and vice versa. Wang et al. [10] [11] split a CU in the same way as in [9], however, hypothesis testing is introduced to examine the significance of the difference in variances.

Usage of AZBs: When an AZB is presented, it generally indicates that the CU can be accurately predicted using the current coding mode and depth. The remaining selection process of coding mode and depth can therefore be skipped. In [12], Jung et al. utilized the inter-layer and spatial correlations to detect AZBs, thus terminating the mode decision process. Pan et al. [13] [14] proposed that the coding mode is considered the best one when the quantized residual coefficients generated by the corresponding merge mode are all zero, then the mode decision process can be early terminated. Chiang et al. [15] determined whether the inter-coding is an AZB based on the Sum-of-Absolute-Difference (SAD) value thus terminating the depth selection process early. Methods in [16] divided CUs into Genuine AZBs (G-AZB) and Pseudo AZBs (P-AZBs). For G-AZB, the AZB decision condition is directly derived from the residual distribution. For P-AZBs, the AZB decision condition is proposed according to the RD cost.

Despite the aforementioned research work, the following issues still need to be investigated. The coding mode or depth selection is closely related to the probabilities of each mode or depth being selected as the best one. The above algorithms did not take this feature into account, which may limit the improvement of the coding speed.

The issues mentioned above motivate us to propose a new AZB early termination algorithm based on probabilistic analysis of coding modes and depths.

3. SSD-BASED AZB DECISION CONDITION

Generally, if a CU is predicted with great accuracy, the generated residual coefficients follow the Laplace distribution with the expectation of 0 and the variance of σ^2 , and the corresponding probability density function is [17]

$$f\left(x\right)=\frac{\lambda}{2}e^{-\lambda|x|} \tag{1}$$

where λ represents the scale parameter of the Laplace distribution. As the expectation is 0, the corresponding variance σ^2 is:

$$D(x)=E\left(x^2\right)-\left(E(x)\right)^2=\frac{\lambda}{2}\int_{-\infty}^{\infty}x^2e^{-\lambda|x|}dx-0=\frac{2}{\lambda^2} \tag{2}$$

According to Eq. (2), we have

$$\lambda=\frac{\sqrt{2}}{\sigma} \tag{3}$$

Assuming that x_{ij} is the residual value at the position of (i,j), the corresponding variance σ^2 is calculated as follows:

$$\sigma^2=D(x_{ij})=E(x_{ij}^2)-\left(E(x_{ij})\right)^2 \tag{4}$$

where $E(x_{ij})$ and $D(x_{ij})$ represent the expectation and the variance of x_{ij} , respectively. As the expectation of the residual coefficient is 0, namely $E(x_{ij})$ is 0. $E(x_{ij}^2)$ can be calculated as follows:

$$E(x_{ij}^2)=\frac{\sum\limits_{i=0}^{N-1}\sum\limits_{j=0}^{N-1}x_{ij}^2}{N^2} \tag{5}$$

SSD is represented by $\sum\limits_{i=0}^{N-1}\sum\limits_{j=0}^{N-1}x_{ij}^2$. Combining Eq. (4) and Eq. (5), we have

$$\sigma^2=\frac{SSD}{N^2} \tag{6}$$

The variance of the DCT coefficients at position (u,v) is

$$\sigma_{dct}^2(u,v)=\sigma^2[\mathrm{ARA}^T]_{uu}[\mathrm{ARA}^T]_{vv} \tag{7}$$

where$[\cdot]_{u,u}$is the value of the coefficient at position (u,u) in the matrix, A is an DCT matrix, A^T represents the transpose of A, and R is the correlation matrix. For a CU of size 8×8, the corresponding R is

$$\mathrm{R}=\begin{bmatrix} 1 & \rho & \cdots & \rho^7 \\ \rho & 1 & \cdots & \rho^6 \\ \vdots & \vdots & \vdots & \vdots \\ \rho^7 & \cdots & \rho & 1 \end{bmatrix} \tag{8}$$

where ρ is the correlation coefficient of the matrix of residual coefficients, and its value ranges from 0.4 to 0.75 [17]. The value of ρ used in [17] is 0.6. The average of σ_{dct}^2 is:

$$\sigma_{\mathrm{dct}}^2=E[\sigma^2[\mathrm{ARA}^T]_{uu}[\mathrm{ARA}^T]_{vv}]=\sigma^2 \tag{9}$$

Combining Eq. (3), Eq. (6) and Eq. (9), we obtain the parameters of the Laplace distribution based on the DCT transform as follows:

$$\lambda_{dct}=\frac{\sqrt{2}N}{\sqrt{SSD}} \tag{10}$$

For the residual coefficients that follow the Laplace distribution, the number of non-zero coefficients generated from quantization is [18]:

$$R(q)=N\times N\times e^{-(1-f)\mathrm{q}\lambda\mathrm{dct}} \tag{11}$$

where f is the rounding offset parameter in the quantization process. In Intra prediction, f generally takes the value of 1/3; while in Inter prediction, f is 1/6. q is the quantization step size. If $R(q)$ in Eq. (11) is less than 1, it means that the coefficients in a block of size N×N are all quantized to zero. Therefore, we can use the following conditions to determine if a block is an AZB:

$$\left(N^2e^{-(1-f)q\lambda_{\mathrm{dct}}}+0.5\right)<1 \tag{12}$$

where 0.5 is the rounding offset. If Eq. (12) holds, the quantized coefficients in an N×N block are all 0. Combining Eq. (10) and Eq. (12), the decision condition for AZB based on SSD is deduced as:

$$\sqrt{\mathrm{SSD}}<\frac{\sqrt{2}\,(1-f)\,qN}{\mathrm{ln}2N^2} \tag{13}$$

The above AZB decision condition is deduced for 8×8 CUs. Similar decision conditions can be obtained for 16×16, 32×32 and 64×64 CUs.

As mentioned above, the coding mode or depth selections are closely related to their probabilities of being selected as the best ones. We need to combine the probability of each mode or depth being selected as the best one to obtain the corresponding decision condition. Suppose α is a parameter, which is determined according to the probability of the current CU adopting a particular mode or depth, Eq. (13) can be revised as:

$$\sqrt{\mathrm{SSD}}<\alpha\cdot\frac{\sqrt{2}\,(1-f)\,qN}{\mathrm{ln}2N^2} \tag{14}$$

It is a key problem to obtain the optimal value for α. Since there are mode selection and depth selection in SHVC, we combine with probabilities of mode and depth to obtain their corresponding optimal α in the following section, respectively.

4. MODE PROBABILITY-BASED ILR MODE EARLY TERMINATION

In our previous research [11], we discussed how to obtain the probability of each particular mode being selected as the best one. We divided the probability range of [0%∼100%] into 5 equal intervals, namely [0%∼20%], [20%∼40%], [40%∼60%], [60%∼80%], and [80%∼100%]. Since probabilities in different intervals are significantly different, we conducted extensive experiment to individually test these five intervals to obtain their corresponding optimal values.

As the coding process of ILR mode is relatively simple and the ILR mode is often adopted by most CUs as the best mode [10], we first evaluate the ILR mode to determine whether the early termination condition is satisfied, thus skipping the Intra prediction. To achieve the decision condition of AZB, α in Eq. (14) is set to common values, e.g. 1, 2, 3, 4, 5, 6, etc when the probability of the ILR mode being selected as the best is 40%∼60%. Experiments show that $\alpha=4$ can obtain the best performance.

Since $\alpha=4$ is not always optimal for all probabilities in [40%∼60%], we take $\alpha=4$ as the optimal value for the median of [40%∼60%], namely 50%. In a similar manner, the optimal α values for 10%, 30%, 70%, and 90% is 1, 3, 6, and 9, respectively. Concatenating the probability and its corresponding optimal value of α, we obtain a series of tuples: $(10\%,1)$, $(30\%,3)$, $(50\%,4)$, $(70\%,6)$, $(90\%,9)$. To investigate the relationship between the probability x and the corresponding optimal value of α, the polynomial regression is applied and the corresponding expression of the fitting function is given as follows:

$$\alpha=20.83\cdot x^3-25.89\cdot x^2+16.93\cdot x-0.4268 \tag{15}$$

Consequently, we can derive the corresponding optimal value of α for any probability of x. Combining Eq. (14) and Eq. (15), we obtain the probability-based early termination conditions for the ILR mode as shown Eq. (16).

$$\sqrt{SSD}<\left(20.83\cdot x^3-25.89\cdot x^2+16.93\cdot x-0.4268\right)\cdot\frac{\sqrt{2}\,(1-f)\,qN}{\ln 2N^2} \tag{16}$$

If the inequality in Eq. (16) holds, the condition of early termination is satisfied, the Intra mode can thus be skipped; otherwise, the Intra mode is required to be examined for further prediction.

5. DEPTH PROBABILITY-BASED EARLY TERMINATION

The same methodology as described for the early termination of the ILR mode is employed. When the coding depth is 1, we obtain a series of tuples: $(10\%, 1)$, $(30\%, 2)$, $(50\%, 3)$, $(70\%, 4)$, $(90\%, 7)$.

The polynomial regression is applied to the five tuples to investigate the relationship between the probability d_1 of coding depth 1 and its corresponding optimal value of α:

$$\alpha = 14.63d_1^3 - 10.47d_1^2 + 4.382d_1 - 0.8997 \tag{17}$$

For coding depth of 2, the relationship between the probability d_2 of coding depth 2 and its corresponding optimal value of α is given as

$$\alpha = 14.83d_2^3 - 13.86d_2^2 + 9.31d_2 - 1.071 \tag{18}$$

The optimal value of α for the coding depths of 1 and 2 can be obtained using Eq. (17) and Eq. (18), respectively. Substituting them into Eq. (14), we can derive the corresponding early termination decision conditions for the coding depths of 1 and 2 to improve the coding speed.

6. EXPERIMENTAL RESULTS

To verify the effectiveness of the proposed algorithm, we employ the reference software (SHM 11.0) on a server with Intel (R) 2.0 GHz CPU and 30 GB memory for testing. The encoding parameters specified in CTC [19] are used. The QP factors for the BL are (26, 30, 34, 38). Two sets of QP factors (20, 24, 28, 32) and (22, 26, 30, 34) are used for the EL. For simplicity, the QP factors of (20, 24, 28, 32) and (22, 26, 30, 34) are denoted as C1 and C2, respectively. The experimental performance is measured in terms of coding efficiency and coding speed. The coding efficiency is measured by BDBR [20] and the coding speed is evaluated by TS, which represents the proportional reduction in encoding time for the EL.

In order to further demonstrate the effectiveness of the proposed algorithms, we compare the performance of our algorithm with EMSIP [10] and HAZSQBD [16]. Table 1 and Table 2 compare the coding performance of the proposed algorithms with that of the state-of-the-art methods.

As can be seen from Table 1, the computation time of the proposed algorithm is decreased by 74.86%, and the computation time of EMSIP and HAZSQBD are reduced by 59.10% and 50.16%, respectively. The BDBR of the proposed algorithm is -0.25, and the BDBRs of EMSIP and HAZSQBD are -0.20 and -0.22, respectively. Compared with EMSIP and HAZSQBD, the proposed algorithm saves additional encoding time of 15.76% and 24.70%, with 0.05 and 0.03 BDBR savings, respectively. As can be seen from Table 2, the computation time of the proposed algorithm is decreased by 75.03%, and the computation time of EMSIP and HAZSQBD is reduced by 59.82% and 51.84%. The BDBR of the proposed algorithm is -0.27, and the BDBRs of EMSIP and HAZSQBD are -0.11 and -0.23, respectively. Compared with EMSIP and HAZSQBD, the proposed algorithm saves additional encoding time of 15.21% and 23.19% with 0.16 and 0.04 BDBR savings, respectively. Therefore, the proposed algorithm is effectively faster than the other three methods under the conditions of C1 and C2.

Table 1. Performance comparison among different algorithms under the condition of C1

Sequence	Proposed		EMSIP [10]		HAZSQBD [16]	
	BDBR(%)	TS(%)	BDBR(%)	TS(%)	BDBR(%)	TS(%)
Traffic	-0.34	84.02	-0.29	53.38	-0.27	49.45
PeopleOnStreet	-0.37	85.48	-0.26	46.13	-0.27	49.11
Kimono	-0.31	74.32	-0.21	69.17	-0.21	51.47
ParkScene	-0.28	57.15	-0.23	55.23	-0.24	49.28
Cactus	-0.22	71.58	-0.28	62.38	-0.25	48.23
BasketballDrive	-0.11	78.94	-0.03	66.41	-0.16	51.05
BQTerrace	-0.09	72.54	-0.08	60.99	-0.12	52.52
Average	-0.25	74.86	-0.20	59.10	-0.22	50.16

Table 2. Performance comparison among different algorithms under the condition of C2

Sequence	Proposed		EMSIP [10]		HAZSQBD [16]	
	BDBR(%)	TS(%)	BDBR(%)	TS(%)	BDBR(%)	TS(%)
Traffic	-0.27	77.11	-0.17	49.95	-0.27	53.12
PeopleOnStreet	-0.22	78.58	-0.07	52.54	-0.29	51.56
Kimono	-0.23	75.63	-0.26	68.95	-0.22	52.52
ParkScene	-0.21	73.51	-0.04	58.12	-0.27	52
Cactus	-0.27	72.78	-0.09	64.58	-0.25	51.21
BasketballDrive	-0.37	73.79	-0.14	62.23	-0.18	48.65
BQTerrace	-0.29	73.82	-0.01	62.35	-0.15	53.81
Average	-0.27	75.03	-0.11	59.82	-0.23	51.84

In Tables 1 and 2, the decrease in BDBR indicates that the coding efficiency improves for all sequences compared with the SHM reference software. To our analysis, this is caused by RD dependency among coding CUs. We have detailed the reason in [11].

7. CONCLUSION

In order to improve the speed of the Intra coding process in QSHVC, this paper proposes an efficient probability-based AZB early termination algorithm. The experimental results demonstrate that the proposed algorithm can significantly improve the speed of video coding while the coding efficiency is slightly improved.

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