Transform Domain Integer Distortion Estimation for HEVC Encoder

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Abstract: High Efficiency Video Coding (HEVC) improved coding performance compared to earlier standard, H.264/AVC, while its computational complexity increased significantly. In order to find the optimal coding mode, Rate Distortion Optimization (RDO) searches all the possible modes to select the one having the minimum rate-distortion cost. The RDO framework shows best performance, but these holds most portion of the encoding complexity. This paper proposes the efficient way to find the optimal mode without a heavy computational burden of the RDO. We propose an integer level distortion estimation in transform domain and it can remove reconstruction processes needed for RDO mode decision. Experimental results show that the proposed distortion estimation can reduce encoding time about 13.9% with a negligible degradation of the Rate Distortion (RD) performance.

1. Introduction

HEVC standard[1] adopted various coding tool to improve the compress performance. Especially, HEVC allows a highly flexible quad-tree coding block partioning with different prediction modes. The optimal mode decision having the best coding gain and quality for all the possible partition sizes and modes has a tremendous computational load during HEVC encoding. Therefore, fast encoding without sacrifying the coding performance is highly needed for real time encoding applications.

To solve this issue, many researches have been developed for fast encoding through reducing candidates of modes or RD cost estimation. The candidates for mode decision process were adaptively selected in [2]-[4]. The RD costs of Intra coding modes were estimated using Hadamard transform in [5] and [6].

In this paper, we propose a fast distortion estimation method in the transform domain and eliminating reconstruction processes(including inverse quantization, inverse transform and adding predicted block) needed for RDO mode decision. For this, we expend our previous work [7] for H.264/AVC to HEVC.

This paper is organized as follows: Section 2 illustrates the conventional RDO mode decision in HEVC reference software [8]-[9]. Section 3 describes the proposed transform domain distortion estimation method. Section 4 demonstrates the proposed methods, and Section 5 concludes this paper.

2. Rate-Distortion Cost of HEVC

RDO Mode Decision selects the best mode having the minimum RD cost described in (1),

$$J_k = D_k + \lambda_k \cdot R_k, \quad (1)$$

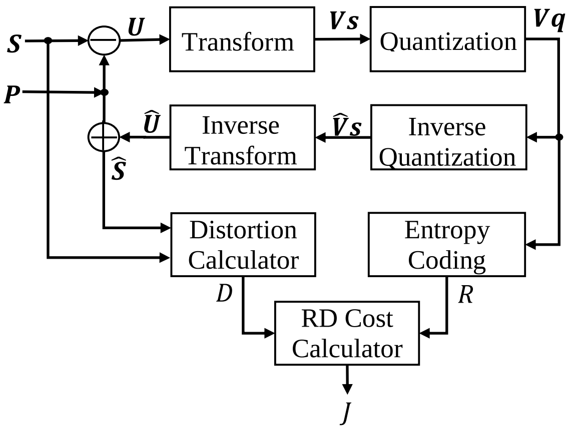

Figure 1. The Processes for Rate and Distortion Calculation.

where k indicates mode k , and R_k and D_k means rate and distortion of mode k, respectively. D_k is calculated as follows.

$$D_k = \sum_{i,j} {d_{i,j}}^2\,,\ where\ \ d_{i,j} = s_{i,j} - \hat{s}_{i,j} \quad (2)$$

In eq. (2), i, j indicates(i, j)th position in the block, and $s_{i,j}$ and $\hat{s}_{i,j}$ refer to (i, j)th pixel of original and reconstructed block. Figure 1 depicts the entire processes for RD cost calculation. In this figure, $\boldsymbol{S}$, $\boldsymbol{P}$, and $\boldsymbol{U}$ mean the original, predicted, and residual block, respectively. For computing distortion, each residual block $\boldsymbol{U}$ should be transformed, quantized, inverse quantized, inverse transformed, and reconstructed by adding predicted block as shown in figure 1. This computation is a quite burden for the entire encoding process, especially for real time encoding.

The quantization of HEVC can be represented as the following equation.

$$\begin{aligned} Vq_{i,j} &= round\left(Vs_{i,j} \div Qstep(QP)\right) \\ &\approx \left(Vs_{i,j} \times F_{QP\%6} + f_Q\right) \gg \left(s_Q + s_T\right). \end{aligned} \quad (3)$$

Here, f_Q, s_Q, and s_T indicate an offset for quantization, $\frac{QP}{6} + 14$, and $15 - B - M$, respectively. And B is a bit-depth of input signal and M is $log_2(TB\_Size)$. The quantization step size, $Qstep(QP)$, for each Quantization Parameter (QP) is defined as

$$\begin{aligned} Qstep(QP) &= g_{QP\%6} \times 2^{QP/6} \\ where\ g_{QP\%6} &= \left\{2^{-\frac{4}{6}}, 2^{-\frac{3}{6}}, 2^{-\frac{2}{6}}, 2^{-\frac{1}{6}}, 2^0, 2^{\frac{1}{6}}\right\}. \end{aligned} \quad (4)$$

For removing division operation during quantization, multiplication factor, $F_{QP\%6}$, was derived by $2^{14} \div g_{QP\%6}$ and used instead of $g_{QP\%6}$ shown as eq. (3).

3. Transform Domain Distortion Estimation

In this section, we propose a transform domain integer distortion estimation method for HEVC as an extension of our previous work [7] on H.264/AVC. Also, we detect Zero Quantized Coefficient (ZQC) before quantization and further reduce the computation for ZQC. The proposed distortion calculation only needs the input signal for quantization, i.e., transformed or transform skipped coefficients for all transform block sizes and all bit-depth. And it can be performed in the quantization process for more computational reduction. Figure 2 shows the block diagram of the proposed method. In this figure, the output of quantization and entropy coding, $\boldsymbol{Vq}$ and R, are the same as that of figure 1.

3. 1 Distortion by the quantization process

From the assumption that the transform of HEVC has energy conservation from time domain, we estimated the distortion in the transform domain as an error by the quantization process. Because the input values for quantization are scaled by 2^{s_T} in HEVC [8]-[9], the differences by the quantization can be represented as

$$V_{i,j} - \hat{V}_{i,j} = Vs_{i,j} \times 2^{-s_T} - Vq_{i,j} \times Qstep(QP). \quad (5)$$

Here, $V_{i,j}$ and $\hat{V}_{i,j}$ means input coefficients for quantization and inverse quantized output of quantized coefficients, $Vq_{i,j}$. The above equation can be written as the following equation using eq. (4).

$$V_{i,j} - \hat{V}_{i,j} = Vs_{i,j} \times 2^{-s_T} - Vq_{i,j} \times g_{QP\%6} \times 2^{QP/6}. \quad (6)$$

And using multiplication factor, $F_{QP\%6}$, in eq. (3), the above equation can be

$$V_{i,j} - \hat{V}_{i,j} \approx \{Vs_{i,j} \times F_{QP\%6} \times 2^{-s_T} - Vq_{i,j} \times 2^{s_Q}\} \times g_{QP\%6} \times 2^{-14}. \quad (7)$$

In order for integer operation, we used scaling factor for inverse quantization of HEVC [1], $G_{QP\%6}$, i.e.,

$$G_{QP\%6} \approx g_{QP\%6} \times 2^6, G_{QP\%6} = \{40,45,51,57,64,72\}. \quad (8)$$

And we can make the following equation.

$$V_{i,j} - \hat{V}_{i,j} \approx \{Vs_{i,j} \times F_{QP\%6} \times 2^{-s_T} - Vq_{i,j} \times 2^{s_Q}\} \times G_{QP\%6} \times 2^{-b}, \quad (9)$$

where, b is $14 + 6$.

Therefore, the estimated distortion by the quantization, $\hat{D}$, can be written as eq. (10).

$$\hat{D} = \left(\sum_{i,j} \hat{d}_{i,j}^{\,2}\right) \times G_{QP\%6}^{\;2} \times 2^{-2b}, \quad where\ \hat{d}_{i,j} = \left(Vs_{i,j} \times F_{QP\%6} \times 2^{-s_T} - Vq_{i,j} \times 2^{s_Q}\right) \quad (10)$$

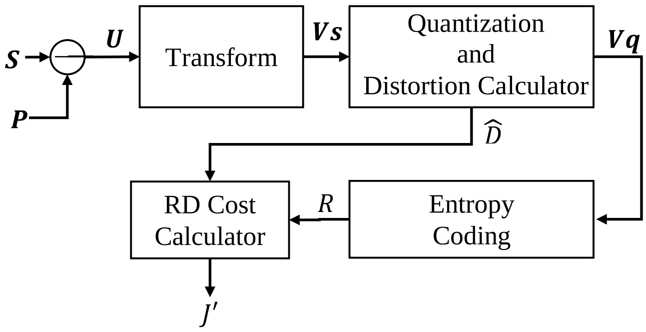

Figure 2. The Processes for Transform Domain Distortion Estimation.

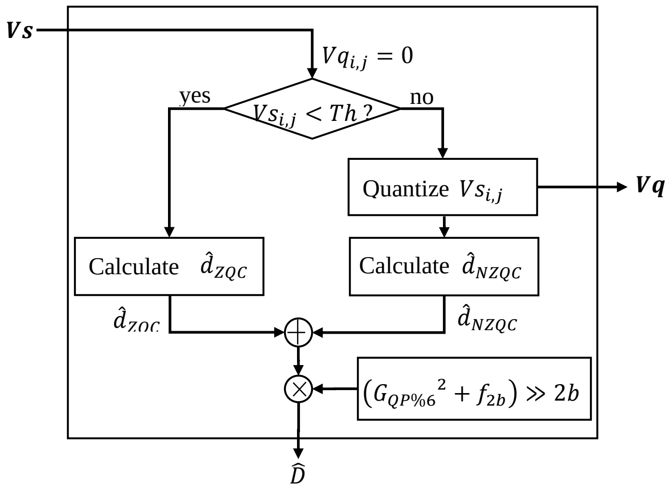

Figure 3. Proposed Quantization and Distortion Calculator.

Because $Vs_{i,j}$, $Vq_{i,j}$, $F_{QP\%6}$, $G_{QP\%6}$, s_T, s_Q, and $2b$ in eq. (10) are all integer values, the distortion can be calculated using integer multiplication and shift operations. Also, scaling factor, $F_{QP\%6}$ and $G_{QP\%6}$ for $QP\%6 = \{0, 1, \ldots, 5\}$ are defined in HEVC quantization, therefore, no additional constant table is needed for eq. (10).

3. 2 Computation reduction for zero quantized coefficient

Because most of the quantized coefficients become zero, we propose a distortion calculation method by detecting ZQC for further computation reduction. From the quantization in eq. (3), we can make the threshold for detecting ZQC.

$$Th = \left[\left(\left(1 \ll (s_Q + s_T)\right) - f_Q\right) \div F_{QP\%6}\right]. \quad (11)$$

The threshold, Th, is a constant for all coefficients in the transform block. If $Vs_{i,j}$ is smaller than Th, there is no need to quantize it. And the distortion of eq. (10) can be modified as

$$\hat{d}_{ZQC} = \left(\sum_{i,j}^{ZQC} Vs_{i,j}^{\;2}\right) \times F_{QP\%6}^{\;2} \times 2^{-2s_T}, \quad (12)$$

here, $\hat{d}_{ZQC}$ means the distortion for zero quantized coefficients. The distortion for Non-zero Quantized Coefficients (NZQC), $\hat{d}_{NZQC}$ can be calculated using eq. (10). Figure 3 shows a flow chart for the Quantization and Distortion Calculator block of figure 2.

Table 1. The RD performance and percentage of time saving of the proposed method.

Class	Sequence	BD-PSNR (dB)	BD-Rate (%)	TS (%)
A	Traffic	-0.0035	0.13	13.6
	PeopleOnStreet	0.0004	-0.01	14.1
	Nebuta	-0.0014	0.08	15.5
	SteamLocomotive	-0.0053	0.27	13.5
B	Kimono	-0.0016	0.07	13.5
	ParkScene	-0.0016	0.06	13.0
	Cactus	-0.0020	0.10	14.4
	BasketballDrive	-0.0011	0.07	13.8
	BQTerrace	-0.0028	0.19	13.2
	Average	-0.0021	0.11	13.9

4. Experimental Results

In order to verify the proposed distortion estimation method, we used HEVC reference software HM16.8 [9]. The simulation environment is Intel(R) Core(TM) i7-4790M CPU @ 3.60GHz 16.0GB RAM system and Microsoft Windows 7 OS. We implemented our scheme to the RDO mode decision for Inter CUs. We tested high resolution sequences of HEVC common test conditions [10] with low delay configuration for QP 22, 27, 32, and 37. Coding performance was measured by BD-PSNR and BD-Rate [11], and saving time was calculated as eq. (13).

$$TS(\%) = \frac{(T_{HM16.8} - T_{proposed\ method})}{T_{HM16.8}} \times 100 \qquad (13)$$

Table 1 shows the RD performance and the percentage of time saving of the proposed method. Simulation results show that the proposed method saved about 13.9% of encoding time with -0.0021 dB of BD-RSNR drop or 0.11% of BD-Rate increase.

5. Conclusions

In this paper, we propose a distortion in the transform domain in order to reduce the computational burden of RDO procedure. In addition to an extension of the previous work for H.264/AVC, we reduce more computations for zero quantized coefficients. By the proposed method, reconstruction process needed for RDO mode decision can be removed. Experimental results show that the proposed method brings about 13.9% of encoding time saving and 0.11% of coding performance loss. We expect that the proposed method can bring more computational gain with rate estimation or other mode decision algorithms.

Acknowledgement

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