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Simplified algorithms for rate-distortion optimization in high efficiency video coding

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ABSTRACT

HEVC is the latest coding standard to improve the coding efficiency by a factor of two over the previous H.264/AVC standard at the cost of the increased complexity of computation rate-distortion optimization (RDO) is one of the computationally demanding operations in HEVC and makes it difficult to process the HEVC compression in real time with a reasonable computing power. This paper aims to present various simplified RDO algorithms with the evaluation of their RD performance and computational complexity. The algorithms for the simplified estimation of the sum of squared error (SSE) and context-adaptive binary arithmetic coding (CABAC) proposed for H.264/AVC are reviewed and then they are applied to the simplification of HEVC RDO. By modifying the previous algorithm for H.264/AVC, a new simplified RDO algorithm is proposed for modifying the previous algorithm for H.264/AVC to be optimized for the hierarchical coding structure of HEVC. Further simplification is attempted to avoid the transforms operations in RDO. The effectiveness of the existing H.264/AVC algorithms as well as the proposed algorithms targeted for HEVC is evaluated and the trade-off relationship between the RD performance and computational complexity is presented for various simplification algorithms. Experimental results show that reasonable combinations of RDO algorithms reduce the computation by 80–85% at the sacrifice of the BD-BR by 3.46–5.93% for low-delay configuration.

1. Introduction

High Efficiency Video Coding (HEVC) [1] is the latest video compression standard developed by ISO/IEC MPEG and ITU-T/VCEG. The HEVC standard aims to improve the coding efficiency over H.264/AVC [2] by a factor of two by adopting several new compression tools including a flexible block structure, the intra-coding with new spatial prediction directions and sophisticated interpolation filters. The improved compression efficiency gives the HEVC a high potential to be adopted by consumer products such as smart phones, security systems, mobile TVs and video conferencing systems which currently use the H.264/AVC as the standard for video compression. Therefore, an efficient implementation of the HEVC standard may give a positive impact on the competitiveness of these consumer products.

The complex coding structure of HEVC makes it difficult to select the optimal mode for the best rate-distortion (RD) performance. Thus, the RDO based on the precise estimation of RD costs is critical to achieve the coding efficiency aimed by HEVC.

For higher coding efficiency, HEVC supports a hierarchical and flexible block structure. The improved coding efficiency is achieved by selecting the best mode that minimizes the bit rate while optimizing the visual quality. The best mode is decided by comparing the Lagrangian cost. The cost evaluation for RDO [3] requires the sum of squared errors (SSE) between the original and reconstructed signals as well as the amount of allocated bits.

$$J = \mathrm{SSE} + \lambda \times \mathrm{Bits} \tag{1}$$

where λ indicates the Lagrangian multiplier which depends on the quantization parameter (QP). In order to evaluate the impact of RDO on the compression efficiency for both H.264/AVC and HEVC, experiments are performed to measure the RD degradation with RDO turned off. For H.264/AVC and HEVC, the reference software JM18.0 [4] and HM5.0 [5] are used respectively. For H.264/AVC, the option turning off the RDO is provided by JM18.0. On the other hand, the same option is not available in HM5.0.

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Table 1
BD-BR increase by turning Off RDO for H.264/AVC and HEVC.

Class C	H.264/AVC BD-BR (%)	HEVC BD-BR (%)
RaceHorses	4.87	12.04
BQMall	4.27	15.17
PartyScene	3.87	10.37
BasketballDrill	3.99	19.08
Average	4.25	14.17

Thus, HM5.0 is modified so that every RDO cost can be replaced by the cost based on the sum of the absolute transformed differences (SATD). It is similar to the option to turn off RDO for H.264/AVC [6].

Table 1 shows the increase in the bitrate by turning off RDO using four sequences in Class C with a resolution of 832 × 480. These four video sequences are selected to cover various video characteristics by ISO/IEC MPEG and ITU-T/VCEG for the performance evaluation. The Bjontegaard-Delta Bitrate (BD-BR) is one of the popular performance metrics to evaluate the efficiency of the video compression tool [7]. Note that a video compression tool generally needs to handle the trade-off relationship between the bit rate and image quality. BD-BR is an efficient metric to measure the balanced efficiency in this trade-off relationship because it evaluates the increase of the bit rate for a fixed video quality. Therefore, BD-BR is used in Table 1 to evaluate the effectiveness of the RDO tool in HEVC. BD-BR for H.264/AVC increases by 4.25% on average, whereas BD-BR for HEVC increases by 14.17% on average. This result shows that the RDO in HEVC is critical and must be used for achieving the high coding efficiency aimed by HEVC.

For H.264/AVC, extensive efforts have been made to reduce the computational complexity of RDO. In [8], context-update dependence is removed for fast execution of context-adaptive binary arithmetic coding (CABAC). A further speed-up is achieved by reducing the number of contexts and by enhancing bin-based parallelism in [9]. In [10], the relationship between the bits and the quantized transform coefficients is modeled for the fast bits estimation of CABAC. In [11], the algorithmic complexity of RDO and CABAC is investigated and a hardware accelerator to reduce it by more than an order of magnitude is proposed. In [12], fast SSE calculation and quantization with look-up tables are proposed and the RD performance is evaluated with the fast estimation of the bitstream length for CAVLC.

The simplified RDO for H.264/AVC has been successful by effectively reducing the complexity without a significant RD degradation. Therefore, this paper attempts to apply the simplified RDO for H.264/AVC to HEVC to evaluate its effectiveness. Since HM5.0 excludes CAVLC, only the simplification for CABAC is considered in this paper. By modifying the RDO for H.264/AVC, this paper also proposes new simplified algorithms for HEVC RDO. The effectiveness of the previous algorithms as well as the proposed algorithms targeted for HEVC is evaluated and the trade-off between the RD performance and computational complexity is presented.

This paper is organized as follows. Section 2 introduces previous research on simplified RDO for H.264/AVC and Section 3 proposes a low-complexity CABAC targeted for HEVC. For further reduction of computational complexity, Section 4 proposes novel algorithms to reduce the transform operations for RDO. In Section 5, various simplified RDO algorithms including those for H.264/AVC and the proposed algorithms in this paper are combined and then the RD degradation and the computation complexity are evaluated by experiments. Finally, conclusions are given in Section 6.

2. Previous research on RDO simplification for H.264/AVC and its application to HEVC

2.1. Experimental conditions

The effect of simplification on RD cost estimation is evaluated with HM5.0 [5]. Four sequences, "Parkscene", "Cactus", "BQTerrace" and "Basketballdrive" in Class B (1920 × 1080) [13] and four sequences, "Racehorses", "BQMall", "PartyScene" and "Basketballdrill" in Class C (832 × 480) [13] are used for evaluation of the RD performance. 20, 24, 28 and 32 are selected as QPs for measuring RD degradation. Asymmetric motion partitioning (AMP) and Non-Square Quad Tree (NSQT) options are turned off and the depth of the transform quad-tree is chosen as 1. Note that the maximum depth for the transform is 3 in HEVC. These encoder options cause a slight impact on the RD degradation which is shown in Table 2. The second and third columns show the BD-BR increases of 1.38% and 2.58% for these configurations, respectively. In HM5.0 reference software, the bits allocated for quantized transform coefficients are calculated twice in function, named xEstimateResidualQT(), and once in another function, named xAddSymbolBitsInter(). For clear explanation, the function names used in the HM5.0 reference software are used in this paper. To simplify experiments, the bits calculated first in xEstimateResidualQT() are used for both the second and third calculations. When all these options are turned off, BD-BR increases by an average of 3.21%. The conditions described above are common to all the experiments reported in this paper.

2.2. Simplified SSE

Fig. 1 presents the operations for HEVC RDO. The input of the RDO operations is the residual signals (R) whereas the outputs are the distortion represented by SSE and the bit rate denoted by Bits in Fig. 1. The generation of the SSE requires a sequence of operations: DCT, quantization (Q), inverse Q (IQ) and inverse DCT (IDCT). The evaluation of the amount of bits needs the DCT and Q followed by entropy coding. In HEVC, CABAC is used as the entropy coding module.

A simplified algorithm to calculate the SSE for H.264/AVC RDO is proposed in [12]. For description of this algorithm, the following notations are used:

S: original signals
RS: reconstructed signals
P: predicted signals

Table 2
BD-BR increase by the options for experiments.

Class C	AMP, NSQT off BD-BR (%)	AMP, NSQT off + transform depth = 1 BD-BR (%)	AMP, NSQT off + transform depth = 1 + one-time calculation for CABAC BD-BR (%)
RaceHorses	0.97	1.88	2.79
BQMall	2.28	3.65	4.40
PartyScene	1.21	2.46	3.06
BasketballDrill	1.08	2.33	2.61
Average	1.38	2.58	3.21