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Quadtree-based non-local Kuan's filtering in video compression

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ABSTRACT

Transform coding has been widely used in video coding standards, such as H.264 advanced video coding (H.264/AVC) and high efficiency video coding (HEVC). But the coded video sequences suffer from annoying coding artifacts, such as blocking and ringing artifacts. In this paper, we propose the quadtree-based non-local Kuan's (QNLK) filter to suppress the quantization noise optimally and improve the objective and subjective quality of the reconstructed frame simultaneously. The proposed filter takes advantage of the non-local Kuan's (NLK) filter to restore the quantized signal in transform domain. Restored coefficients are then projected onto designed quantization constraint sets (QCS). Quadtree-based signaling strategy is used at the end of QNLK for adaptive filtering on/off control. Experimental results of QNLK show that the proposed method achieves significant objective coding gain and visual quality improvement, compared with both H.264/AVC high profile and HEVC.

1. Introduction

Video coding scheme composed by transform coding, predictive coding and entropy coding is often called hybrid video coding which is adopted into most of video coding standards including H.264/AVC [1] and HEVC [2]. Due to the coarse quantization used in the hybrid coding scheme, some annoying artifacts may occur in the reconstructed frame, such as blocking and ringing artifacts. In H.264/AVC, the deblocking filter (DBF) [3] was adopted to alleviate blocking artifacts. DBF operates by detecting the artifacts around the coded block boundary and attenuating them by applying a selected low-pass filter. Although the subjective quality of the reconstructed signal can be improved, the improvement of the objective quality was not obvious and the decoder complexity is increased significantly. Except for DBF, adaptive loop filter (ALF) [4] which is based on the linear Wiener filter has also been proposed to further suppress the quantization noise. As a significant number of bits are required for the representation and transmission of filter coefficients, only one set of filter coefficients is used for the entire frame. Therefore the ALF can reduce the average distortion of each frame globally, but it cannot adapt to different local regions within a frame. To deal with this problem, a variety of adaptive methods which consider different local characteristics within a frame have been developed. Block-based adaptive loop filter (BALF) [5], which only applies the adaptive loop filter on selected blocks was first proposed. Based on BALF, quadtree-based adaptive loop filter (QALF) [6] which is one of the coding efficiency improvement tools in the key technical area (KTA) software [7] was proposed. By introducing quadtree block partitioning, the block control scheme was made more flexible and adaptive.

High efficiency video coding (HEVC), version 1 of which has just been finalized, is the newest video coding standard. In HEVC, two loop filters namely a deblocking filter (DBF) [8] followed by a sample adaptive offset (SAO) [9] operation are applied into the coding loop. In accordance with the H.264/AVC, HEVC also adopts DBF to reduce the blocking artifacts, whereas SAO is a brand new technique. The concept of SAO is to reduce the distortion by first classifying reconstructed signals into different categories, obtaining an offset for each category, and then adding the offset to each sample of the category. The offset value should be explicitly signaled to the decoder and the classification is performed at both the encoder and decoder. Although ALF is not included in the version 1 of HEVC, it has been thoroughly studied during the standardization period. ALF is located just after DBF and SAO. Similar as ALF in H.264/AVC, the ALF for HEVC uses Wiener-based adaptive filter while many of the implementation details have been improved. Two modes, namely low-latency mode and high-efficiency mode, are provided in ALF for different kinds of application. Experimental results show that ALF can achieve 7% average bit rate reduction for HD sequences and can sometimes provide subjective quality gain on top of SAO.

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The scheme of DBF +QALF in H.264/AVC and DBF +SAO+ALF in HEVC can achieve the state of the art performance in terms of both fidelity (PSNR) and visual perception. However, the local statistics of a picture has not been fully explored. In this paper, we propose a method called quadtree-based non-local Kuan's (QNLK) filter which achieves better performance by further exploiting the local statistics within a frame. Fig. 1 shows the block diagram of hybrid video coding with the proposed QNLK loop filter at encoder and decoder.

The core of QNLK is the Kuan's filter [10] which is designed to achieve linear minimum mean square error (LMMSE) estimation. To improve the accuracy of parameter estimation in Kuan's filter, non-local estimation technique [11] and quantization constraint sets (QCS) are adopted to formulate the non-local Kuan's filter (NLK). At the last stage of QNLK, quadtree-based filtering on/off control is carried out to ensure an optimal rate-distortion (RD) performance. The key features of QNLK lie in three aspects. First, QNLK can minimize the Mean Square Error (MSE) between the original and reconstructed frame while keeping local adaptivity simultaneously. Second, QNLK is performed in transform domain and its input signal is the residual transform coefficients. The advantage of this setting will be illustrated in Section 2.

The remainder of this paper is organized as follows. In Section 2, we describe the problem formulation and propose QNLK loop filter. Section 3 presents the detailed algorithm and parameter setting of QNLK. The experimental results and computational complexity analysis are shown in Section 4, where we also examine the correctness of the proposed noise model. Finally, we draw conclusions in Section 5.

2. Problem formulation and the proposed method

Transform coding using DCT first transforms each residual block into the DCT coefficients which are then quantized according to the quantization parameter (QP). Generally, quantization is performed on each block independently and the levels and characteristics of the quantization errors may differ from one block to another. As a result, the blocking artifacts arise as abrupt changes across block boundaries and are especially obvious in smooth regions. In addition, edges become blurred and may even contain ringing effects due to the truncation of high frequency coefficients.

If quantization errors are assumed to be the only source of distortion in the entire encoding procedure, the compression operation can be modeled as a distortion process that adds quantization noise n_q to the original DCT coefficients x

$$y = x + n_q \tag{1}$$

Based on this observation model, the problem of loop filtering can be formulated as: given the compressed transform coefficients y and the quantization parameter QP, we are to estimate coefficients $\hat{x}$, based on some reasonable assumptions of the original coefficient x and the quantization noise n_q. $\hat{x}$ is expected to be closer to x and can bring better visual quality than y. We choose to solve this problem within the classical optimization framework of minimum mean square error

$$\hat{x} = \underset{f(y)}{\operatorname{argmin}} \mathbb{E}\left[\|x - f(y)\|^2\right] \tag{2}$$

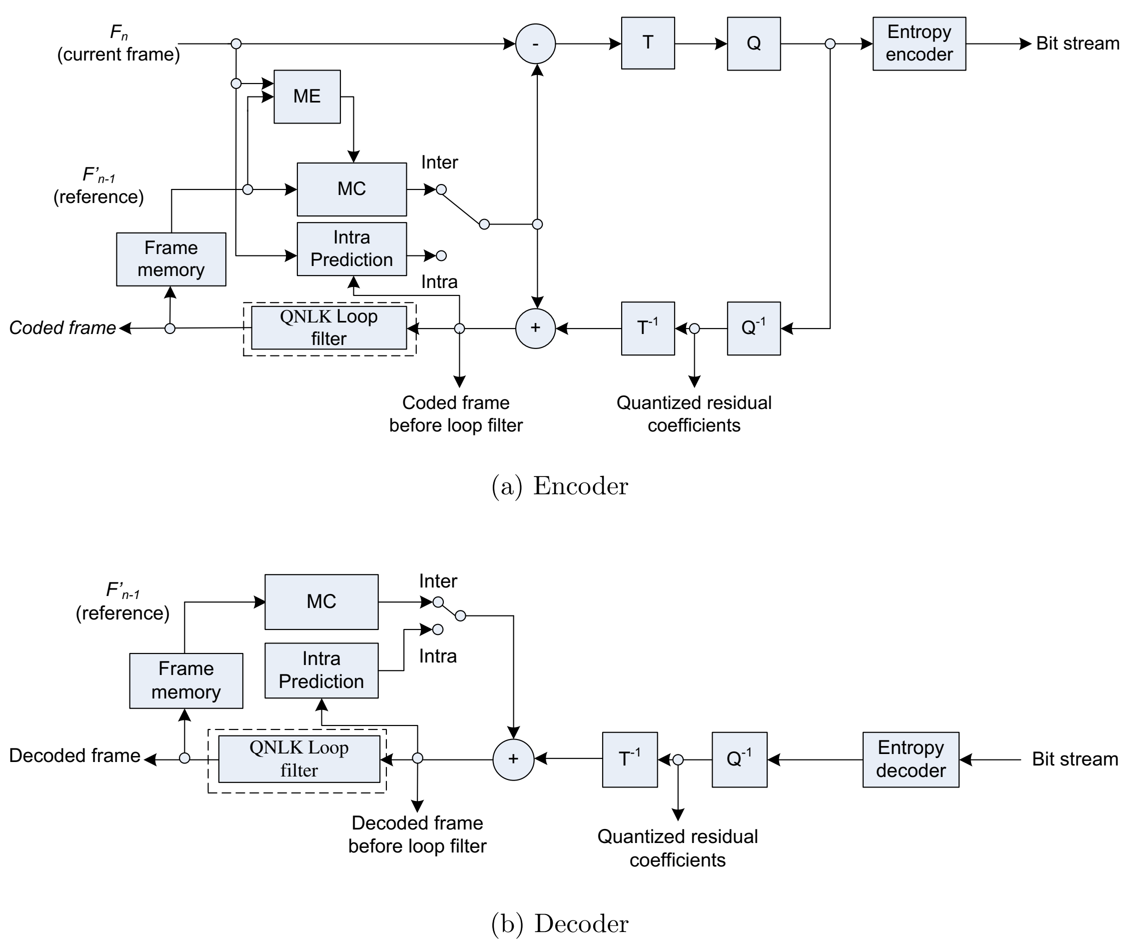

Fig. 1. The block diagram of encoder and decoder with the proposed QNLK loop filter. ME: motion estimation. MC: motion compensation. T: transform. Q: quantization.