Optimizing the Deblocking Algorithm for H.264 Decoder Implementation

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Abstract

In the emerging H.264 video coding standard, a deblocking/loop filter is required for improving the visual quality of the decoded frames. These filters attempt to remove the artifacts introduced by the block-based operations, which are DCT and motion compensation prediction. Although the deblocking filter performs well in improving the subjective and objective quality of output video frames, they are usually computationally intensive. Various deblocking filters operating on spatial or transform domain data was proposed. In this survey, I am discussinging three key classes of proposed deblocking filters, which are projection on convex set (POCS) based filters, weighted sum on symmetrically aligned pixels based filters and adaptive filters. Qualitative comparison will be given on their computation and implementation complexity as well.

Introduction

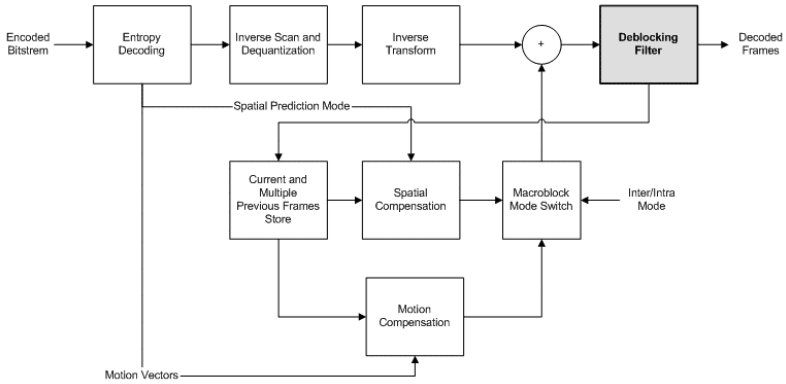

Fig.1 Block diagram of H.264 decoder

In the emerging H.264 video coding standard, a deblocking filter process is required for improving the visual quality of the decoded frames [1]. Each video frames are divided into 16x16 pixels blocks called macroblocks. The deblocking filter is applied to all the edges of 4x4 pixels blocks in each macroblock except the edges on the boundary of a frame or a slice. For each block, vertical edges are filtered from left to right first, and then horizontal edges are filtered from top to bottom. The decoding process is repeated for all the macroblocks in a frame.

A major challenge in designing blocking artifact detection is the detection of true edges in an image. Blindly applying a low pass filter would remove most of the blocking artifacts, but blurring the image as well.

According to an analysis of run-time profiles of decoder sub-functions reported in [2], this deblocking filter process is the most computationally intensive part that took as much as one-third of computational resources of the decoder.

The algorithms proposed so far, which will be discussed in the next section, are based on complex mathematical derivations to identify and remove the block artifacts. Although significant improvement in subjective and objective quality can be achieved with them, their computation and implementation complexity is so high that prohibits them from being adopted directly in a real time application such as H.264 decoder.

Proposed Algorithms

There are a number of deblocking algorithms proposed for reducing the block artifacts in block DCT based compressed images with minimal smoothing of true edges. They can be classified into regression-based algorithm[4], wavelet-based algorithms [15], anisotropic diffusion based algorithm[14], weighted sum of pixels across block boundaries based algorithm[10][12][16], iterative algorithms based on projection on convex sets (POCS)[5][6][18], and adaptive algorithms [3]. An interesting approach of recasting the deblocking problem into a denoising problem by injecting uniform random noise was also proposed in [13]. While these algorithms operate on the spatial domain, algorithms that work on the DCT transformed domain were proposed in [8][9] and [11]. Among the algorithms proposed, there are 3 key classes of algorithms which based on projection on convex sets (POCS), weighted sum of pixels across the block boundaries, and adaptively applying different filters.

Projection on Convex Sets (POCS) based Iterative Algorithms

This class of algorithms is originated from the image restoration algorithm proposed in [6]. A number of constraints, two in most cases, are imposed on an image to restore it from its corrupted version. After defining the transformations between the constraints, the algorithm starts in an arbitrary point in one of the sets, and projecting iteratively among them until convergence. In [5], mean square error (MSE) is used as a metric of closeness between two consecutive projections. Convergence can be imagined as achieving an MSE below a certain threshold value. If the constraints are convex sets, it is claimed in [6] that a convergence is guaranteed if the intersection of the sets is non-empty.

This approach was proposed the first time in [5] to apply to deblocking of images. In the paper, the constraint sets chosen are the frequency band limit in both vertical and horizontal directions (known as filtering constraint) and the quantization intervals of the transform coefficients (referred to as quantization constraint). In the first step, an image is bandlimited by applying a low-pass filter on it. After that, the image is transformed to obtain the transform coefficients, which are then subjected to the quantization constraint. The coefficients lying outside of the quantization interval are mapped back into the interval. For example, the coefficients can be clipped to the minimum and maximum value if it is outside the interval. This two steps process will be done iteratively until a convergence is reached. The authors claimed that the algorithm converges after about 20 iterations in their experiments.

Due to the iterative nature of this class of algorithm, time to convergence is in fact unknown. This prohibits it from applying on a real time system, which run time of each module must be bounded. The number of iterations may be bounded regardless of convergence, but the quality of deblocking becomes an unknown. Also, the projections involve filtering of the picture and transformation to frequency domain which take unacceptably large amount of extra resources.

Weighted Sum of Symmetrically Aligned Pixels

In the second class of algorithms proposed, the value of each pixel in the picture is recomputed with a weighted sum of itself and the other pixel values which are symmetrically aligned with respect to block boundaries. In [10], the authors proposed a scheme of including 3 other pixels which are taken from the block above, to the left and the block above the left block. The weights are determined empirically and can either be linear or quadratic. The combined effect of these weighted sums on the pixels can be regarded as an interpolation across the block boundaries. However, there is a problem in this approach when a weighted sum of a pixel in a smooth block takes the pixels in the adjacent high-detail blocks into account. The texture details get into the smooth region and a vague image of the high-detail can be seen. This new artifact is referred to as 'ghosting' by the author. A scheme of 'grading' each block according to the level of details with a grading matrix was proposed to minimize this new artifact. The weights on each of the 4 pixels are then increased or reduced according to the grades.

The execution time is guaranteed as the operations are well defined. Since the pictures must be graded before applying the filter on the pixels, a 4 passes scheme for processing a picture was proposed. This algorithm is essentially performing a filtering operation on every pixel in a picture, with the 3 passes of matrix operations in the grading process. It is expect that a very high performance platform is required to implement this algorithm in a real time application.

Adaptive Deblocking Filter

In this class of algorithm, the deblocking process is separated into two stages. In the first stage, the edge is classified into different boundary strength with the pixels along the normal to an edge. In the second stage, different filtering scheme is applied according to the strengths obtained in stage one. In [3], the edges are classified into 3 types to which no filter, weak 3-tap filter and strong 5-tap filter are applied. The algorithm is adaptive because the thresholds for edge classification are based on the quantization parameters included in the relevant blocks. An edge will only be filtered if the difference between the pixel values along the normal to the edge, but not across the edge, is smaller than the threshold. For high detail blocks on the side of edges, the differences are usually larger and so strong filtering is seldom applied to preserve the details. As the threshold increases with the quantization parameters, the edges across the high detail blocks will be filtered eventually because a high coding error is assumed for large quantization parameters.

Since the edges are classified before processing, strong filtering can be replaced by weak filtering or even skipped. Also the filtering is not applied to every pixel but only those across the edges. A significant amount of computation can be saved through the classification. A disadvantage of this algorithm is the higher complexity in control flow of the algorithm.

Summary on Relative Complexity

	POCS-based algorithm[5]	**Weighted sum based algorithm[10]**	**Adaptive algorithms [3]**
Algorithm Flow	*Iteratively projecting back and forth between two sets on whole picture*	*Grading of blocks with grading matrix Iterative on every pixels*	*Iteratively classify and applying filter on every block edges*
Major Operations	*Low-pass filtering Discrete Cosine Transform*	*Weighted Sum of 4 pixels for each pixel*	*3-tap or 5-tap filter on pixels across edges*
Relative Computation Complexity	*High*	*Medium*	*Low*
Relative Implementation Complexity	*High*	*Low*	*Medium*

Table 1. A summary on the computation and implementation complexity

The relative computation and implementation complexity of the three key classes of algorithm discussed is summarized qualitatively in Table 1. The POCS-based algorithms is considered the most complex algorithm because the flow complex and major operations are much more intensive than the other two. The major operations for the weighted sum based algorithms and the adaptive algorithm seems to be similar. For the case of 4x4 pixels blocks, the major operation performed by adaptive algorithms is only about half of that by the weighted sum based algorithms. The adaptive algorithm is considered more complex in implementation because of its classification and applying different filters adaptively.

Proposed Works

A heuristic algorithm that can achieve a near-to-optimal quality and be implemented in a simpler software or hardware may be a good alternative to an optimal algorithm which is complex to realize. The new design will be implemented and experimented on an open source H.264 codec (JM93). A comparison on the decoded frame quality with the other algorithms will be presented in terms of PSNR and some recently proposed image quality measures such as SSIM[19]. A comparison on the computation requirements between the proposed algorithm and the original algorithm that comes with the source in terms of the common operations will be reported as well.

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