Blocking Artifacts Reduction with Constrained Random Modification of Block Boundary Pixels

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Abstract: Low bit rate image/video coding is essential for many visual communication applications. When bit rates become low, most compression algorithms yield visually blocking artifacts that highly degrade the perceptual quality, and post-processing approaches provide one attractive solution. In this paper, we provide simple and very efficient blocking artifacts reduction method using constrained random value addition. Our method is simple enough to be used for real-time post-processing of video.

1. Introduction

Block-based transform coding has been widely used in many image compression applications; for example, the motion-compensated DCT has been recently adopted in the international standards of H.261, JPEG, and MPEG. Block-based transform coding may cause the so-called blocking artifacts along block boundaries. The blocking artifacts can be severe when the transform coefficients are relatively coarsely quantized in a plain, or very slowly varying part of images. A number of works for reducing the artifacts have been reported. One approach is to allow blocks overlapped so that coding of adjacent blocks can be dependent in some degree [1]. Another approach considers the visibility of blocking artifacts is due to spatially high frequencies of block discontinuity, and applies the low pass filtering to those pixels along block boundaries [2-4]. Several different filters were applied by T. Jarske et al. [4] to observe that the Gaussian low pass filter with high frequency emphasis gave the best performance. Recently, there have been two very similar approaches: the theory of projections onto convex sets (POCS) [5] and the constrained least-square method [5,6]. These approaches reconstruct images using prior knowledge about the smoothness of the original image. Yang et al. [5] used prior knowledge of bounded quantized transform coefficients and the pixel differences over block boundaries. The reconstructed image was obtained in an iterative way by forcing this prior knowledge alternately on the reconstructed image. Zakhor [6] used two constraints in the constrained minimization approach: the quantization and the band-limitation constraints. Another interesting approach, which has been recently developed, is to use the DCT kernel functions as the basis of the compensation terms for blocking artifacts reduction [7,8]. It finds the DCT coefficients of the correction terms to minimize the block boundary discontinuity. There is a filtering approach also in wavelet domain, however, despising the additional computational burden of performing forward and inverse wavelet transform, direct manipulation of the wavelet coefficients may lead to the danger of introducing wavelet-specific artifacts [9].

This paper takes a little bit different approach compared with the previous ones in that it proposes to add constrained random values to the block boundary pixels. We are motivated by the fact that the blocking artifacts are most conspicuous when the discontinuity of pixel values across block boundaries is prolonged horizontally and/or vertically. As far as the human perception is concerned, a few places (probably scattered ones) of level difference in block boundaries do not really matter unless they are structured. In other words, the structurally prolonged discontinuity pattern is the real culprit for titling appearance of a reconstructed image. This notion is supported by the previous research in [10]. The block diagram of the proposed method is in Fig 1.

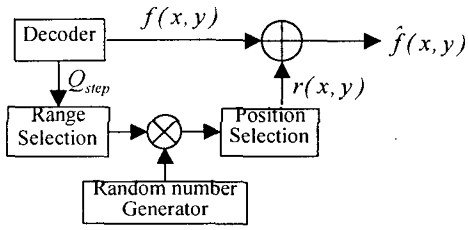


Figure 1. Proposed Blocking Artifacts Reduction method

In this paper, we propose to add random values to block boundary pixels in a *controlled* way so that any horizontally or vertically structured tiling effects are kept minimally noticeable. One constraint we can put in action is that the absolute quantization error is limited within half of the quantization step size. Note that the quantization is performed in the transform-domain and the quantization error is thus associated to the transform coefficients, not to their spatial pixel values. Since we add random values in spatial domain, we need to come up with some way to decide the range for the added random value. This paper will discuss how to optimally decide the range for the added random value. Once the range is decided, random values uniformly distributed over [-0.5, +0.5] are multiplies by the value. The weighted random number $r(x,y)$ is added to the pixels along block boundaries.

According to our tentative experimental observation, the image reconstructed by adding the weighted random values $r(x,y)$ sometimes show speckles along block-boundaries, although the blocking artifacts is significantly reduced. To alleviate this side effect, we control the width of addition. One great advantage of the proposed method is that it can be additionally combined with the existing blocking artifacts reduction technique to further improve the performance. That is, the reconstructed image $\hat{f}(x,y)$ can be further subjected to the traditional low-pass filter type blocking artifacts reduction techniques.

2. Removal of Blocking Artifacts using Random Value Addition

The goal of our research is to develop a better way of removing blocking artifacts while keeping the complexity of computation within an acceptable level. Specifically, our goal is to develop an algorithm that meets the following criteria:

1. Be robust with respect to introducing additional artifacts, such as new blocking artifacts [11,12].
2. Be adaptive so as to successfully remove different levels of blocking artifacts.
3. Do not give an appearance of over-smoothing the image textures while successfully removing blocking artifacts [12].
4. Be computationally efficient so as to be able to perform in video post-processing and other real-time video applications.

To meet the above requirements we developed a simple method for removing blocking artifacts based on spatial variable width modification using random value addition.

2.1 Algorithm overview

Our algorithm removes artificial block-boundary discontinuities by variable-width one-dimensional modification first which is carried in the vertical direction and then in the horizontal direction. For each of the two stages of modification, the steps of the algorithm are as follows:

STEP 1 find blocks where blocking artifacts occurs.

STEP 2 find the width of pixel modification, i.e., the number of pixels before and after the block boundary whose values are to be altered.

STEP 3 find the initial values of modification as the values that should be used to modify pixel values of the reconstructed image so as to minimize the discontinuity between the image pixels within the modification range.

STEP 4 randomize the *initial* values of the modification, so that it adds constrained random values.

STEP 5 modify the pixels within the selected range (width), i.e., add the randomized values to the corresponding pixels of the reconstructed image on both sides of the block boundaries.

2.2 Detecting blocking artifacts

In our method, we determine the presence of blocking artifacts by performing three sets of comparison.

$$d_{AB} = \frac{1}{N}\sum_{k=0}^{N-1}(a_k - b_k) \tag{1}$$

where a_k and b_k are the kth pixel value in the block A and B, respectively. First, we look at the average difference across the boundary of the block, d_{AB} (see Fig. 2) and compare its value with a threshold. If the value of d_{AB} is less than its threshold, we go to the next step. In the second step, we look at the direction if the changes across the block, then we go to the third step. Finally, we look at the variance of the d_{AB} across the rows/columns of the block, v_{AB}. If the value of v_{AB} is lower than its threshold then the block boundary is identified as exhibiting blocking artifacts.

2.3 Determining the width of modification

To determine the width of modification, we first identify the maximum possible width of modifying pixels before and after the boundary and then select a portion of the maximum width to be the final width as shown in Fig. 2. Based on our experiments we set the maximum possible width as

$$w_{\max} = \mathrm{int}\left(\frac{N-1}{2}\right) \tag{2}$$

where N is the horizontal and vertical block size. The second step is carried out based on the characteristics of block discontinuity. The width w is

$$w = i \quad \text{if } (i-1)\frac{d_{AB\_\max}}{w_{\max}} < d_{AB} \le i \cdot \frac{d_{AB\_\max}}{w_{\max}} \tag{3}$$

where $1 \le i \le w_{\max}$

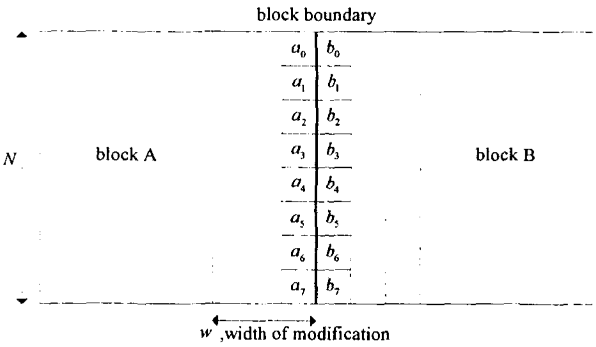


Figure 2. Width of modification for vertical block boundary (N=8, w=3)

2.4 Determining the initial modification values

After the width of modification is determined, we find the initial values of the modification. These values will be used to alter (by summation or subtraction) the pixel values of the reconstructed image. The initial values are found for each row/column across the block boundary as the values that minimize the pixel discontinuity within the area covered by the range of modification as shown in Fig.3. The modification corresponds to the minimum range between the pixels that is possible to achieve given the modification width, w and the value of the boundary discontinuity, d. The minimum possible range is determined as follows

$$h_{\min} = \frac{w}{|d|} \tag{4}$$

The initial modification value is

$$p_{init} = p_o + \frac{1}{2} n \cdot \frac{w}{d} \quad \text{where } 1 \le n \le 2w \tag{5}$$

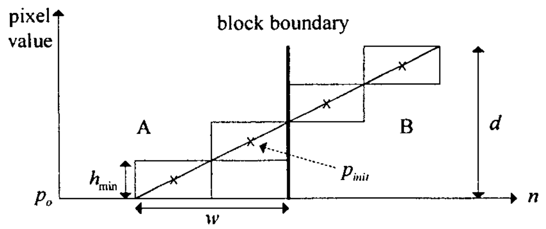


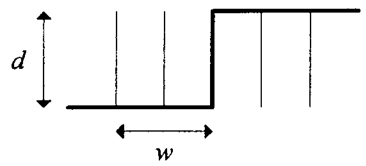
Figure 3. Initial modification value (N=4, w =2)

2.5 Randomizing the modification values

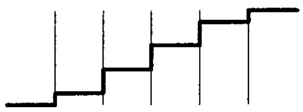
It is well known that the human eye's sensitivity is much greater to the discontinuities that are visually represented through geometric patterns. In order to remedy the above problem, our algorithm randomizes the initial modification values so as not to avoid creating 'geometric looking" patterns in the post-processed image. The weighted random value is added to the pixels along block boundaries to defeat geometric pattern as shown in Fig. 4. The modification value is,

$$p_{disp} = (1 + h_{\min} \cdot r(x,y))p_{init} \tag{6}$$

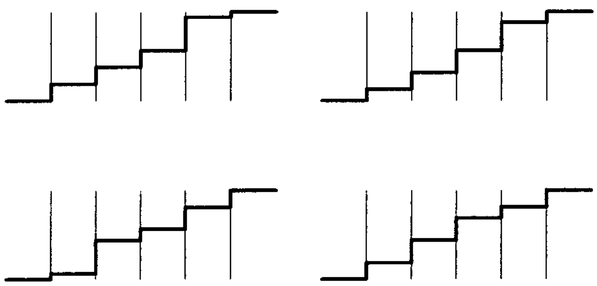
The random values, $r(x,y)$ are uniformly distributed over [-0.5, +0.5].



(a) Block boundary discontinuity



(b) Initial modification value



(c) Randomized modification value

Figure 4. Randomizing the modification values (N=4, w =2)

2.6 Modifying the pixels

Finally, the randomized values are transformed into the actual values of the modification to be added to or subtracted from the pixel values of the input blocky images.

3. Experiments and Discussion

To demonstrate the performance of the proposed method, we applied our algorithm on the Lena and Susie images which were compressed by the PVRG JPEG [13] and by the MPEG-1 I-picture, respectively. In JPEG coding, the block size was 8x8 and PVRG QF was set to 200, which produced a compression ratio of 33.66, resulting in 0.24 bit/pixel. In MPEG-1 intra-coding of the Susie image (16th frame), the compression ration was 48.61, resulting in 0.16 bit/pixel.

From the point of view of the subjective image quality, the proposed algorithm significantly improves the visual quality of output image. In Fig. 5, we illustrate the subjective performance of our algorithm, showing the JPEG-encoded Lena image and MPEG-encoded Susie image with and without post-processing step. The post-processing approaches were successful in reducing the jump in pixel value across the block boundary; that is, the transition over block boundaries became smooth.

Table 1 and 2 show the PSNR results achieved by the previously proposed methods and our method. The block discontinuity was considerably reduced after the post-processing, and the PSNR was found, in general, slightly lowered. However, the visual look was significantly enhanced after the proposed post-processing.

4. Conclusion

We have proposed a spatial domain blocking artifacts reduction method based on adding constrained random value. Our algorithm is works well with severe blocking artifacts. Our algorithm is very simple and thus can be used in real time video application.

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Table 1. PSNR Results of Lena Image

Post-processing method	PSNR [dB]
dequantized (without post-processing)	31.23
3x3 Gaussian Low pass filter [4]	31.89
DCT kernel based method [8]	30.78
proposed method	31.32

Table 2. PSNR Results of Susie Image

Post-processing method	PSNR [dB]
dequantized (without post-processing)	33.93
3x3 Gaussian Low pass filter [4]	34.27
DCT kernel based method [8]	33.48
proposed method	33.91

(a) JPEG encoded Lena Image at 0.24 bit/pixel

(b) Lena Image after post-processing

(c) MPEG encoded Susie Image at 0.16bit/pixel

(d) Susie Image after post-processing

Figure 5. Subjective performance results