REMOVAL OF BLOCKING AND RINGING ARTIFACTS IN TRANSFORM CODED IMAGES

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ABSTRACT

Presently Block-based Discrete Cosine Transform (BDCT) image coding techniques are widely used in image and video compression applications such as JPEG and MPEG. At a moderate bit rate, BDCT is usually a quite satisfactory solution to most of practical coding applications. However, for high compression it produces noticeable blocking and ringing artifacts in the decompressed image. In this paper, we propose a novel post-processing algorithm to remove the blocking and ringing effects at low bit rate. The main steps in this algorithm include block classification, boundary low-pass filtering and mid-point interpolation, edge detection and filtering, and DCT coefficient constraint. The improvement is demonstrated both subjectively and objectively.

1. INTRODUCTION

Transform-based data compression is by far the most popular choice both in still image compression and video compression. Among various transforms, Block-based Discrete Cosine Transform (BDCT) is the dominant one because of its near-optimum energy compaction property and availability of fast algorithms and hardware. Therefore, the BDCT is used in most of the current standards such as JPEG and MPEG. The BDCT based coding can successfully compress images by a factor around 10 with nearly no perceptible effects. However, some well-known artifacts arise at low bit rate compression. The two most obvious artifacts in a low bit coded image are "blocking" and "ringing" effects.

In the past two decades, a variety of efforts have been made to remedy these problems, primarily in two major categories: At the encoding end, different encoding schemes have been proposed to avoid such artifacts. In [1], a block overlap method was proposed to reduce blocking effect. In [2], the edge blocks are detected from non-edge blocks and then these two types of blocks are coded differently to remove ringing effect. A DC calibration scheme appeared in [3] uses the anchor blocks and code their DC components error-free for blocking effect removal. At the decoding end, different post-processing algorithms have been suggested to reduce such artifacts. In [1], a simple low-pass filter was used to smooth the unwanted discontinuities at or near the block boundaries. Edge based adaptive filtering post-processor appeared in [4] and [5]. Another approach for reducing coding artifacts is to use image restoration theory. Proposed methods include convex projections (CP) [6, 7, 8], and maximum *a posteriori* (MAP) estimation [9].

Despite various progress reported at the encoding end, changing encoding schemes means to abandon well-accepted JPEG or MPEG standards, which makes research on these progress strictly in academia.

In contrast, post-processing approaches at the decoding end have good potential to be integrated into image and video communications, as they are applied to JPEG and MPEG standards.

In this paper, we will propose a new post-processing artifacts removal algorithm which lies at the decoding end. Our new approach uses both spatial and transform domain methods to remove blocking and ringing artifacts at low bit rate. And this algorithm can achieve the improvement under both objective and subjective criteria.

The rest of this paper is organized as follows: Section 2 describes the proposed algorithm in detail. The objective and subjective simulation results are shown in Section 3. Finally, Section 4 briefly discusses the conclusions and future works.

2. POST-PROCESSOR DESIGN

For the block-transform encoded image, the blocking artifact appears not only on the block boundaries but also in their neighborhood. It may improve the peak signal-tonoise ratio (PSNR) by simply smoothing the block boundaries, but it can not reduce the blocking artifact as much as desired, and the ringing artifact appears along sharp edges in the blocks. It is an important step to detect these edges for ringing artifact reduction. Our proposed algorithm includes these main steps: block classification, blocking artifact removal, ringing artifact removal, and fidelity constraint. The algorithm details are described as in following sections.

2.1. Block Classification

We know that blocking and ringing effects do not appear significantly in every block of a coded image at low bit rate. This can be seen in Fig. 2, which is the JPEG encoded "Lena" at 0.25 bits/pixel (bpp). The original "Lena" picture is also given in Fig. 1 for comparison purpose.

In order to remove blocking and ringing effects, first, we have to detect areas that have blocking or ringing artifacts. It is clear that blocking artifacts are more visible in the low frequency blocks and ringing artifacts show up along the sharp edges, in other words, in the high frequency blocks. In our approach, we use the method similar to [4] to classify the low frequency and high frequency blocks in the transform coefficient domain. A block is marked as low frequency block if

$$C_{DCT}(i,j) * K_{low} = \hat{0}. \tag{1}$$

Similarly, a block is marked as high frequency block if:

$$C_{DCT}(i,j) * K_{high} \neq \hat{0} \tag{2}$$

where C_{DCT} is the 8×8 block of quantized DCT coefficients of block (i,j). $*$ is the element-by-element multiplication. K_{low}, K_{high} are the test matrices for detection of low frequency block and high frequency block, respectively, and $\hat{0}$ is the 8×8 matrix of zeros.

Figure 1. The Original "Lena" Picture

Figure 2. The JPEG encoded "Lena" at 0.25 bpp

After a series of experiments, we choose

$$K_{low} = \begin{bmatrix} 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \tag{3}$$

and

$$K_{high} = \begin{bmatrix} 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}. \tag{4}$$

With this choice, we can locate the blocks with visible blocking effects and ringing effects in the JPEG encoded pictures at low bit rate.

From the results we got from different test images, the above technique works well and has little calculation. The following post-processing steps can rely on it.

2.2. Removal of Blocking Artifacts

2.2.1. Block Boundary Filtering

It can be observed that the pixels on the block boundaries exist discontinuity whether this block belongs to the blocking blocks or not. In order to achieve smaller mean-squared error (MSE), we can apply block boundary filtering for all the blocks in the picture. On the other hand, we have less calculation if we only smooth the blocking block boundaries. The performance of the latter is only slightly worse than the previous one.

The discontinuity at all the block boundaries can be simply lowpass filtered. The mask for this filter [5] is shown in Fig. 3. For the pixels at block boundaries but not at corners, the 2×1 mask with filter coefficients 0.75 and 0.25 is used. As for the pixels at corners of the block, a 2×2 mask with filter coefficients 0.5, 0.25, 0.25, and 0 is used. With this simple space-variant filter, the discontinuity between blocks can be significantly reduced.

2.2.2. Mid-point Displacement Interpolation

Block boundary filtering can only reduce the discontinuity across the boundaries and cannot touch the pixels inside the blocks. In fact, a good result in block effect removal cannot be achieved if we only deal with the pixels on the block boundary area. The reason for this is that the DC coefficient in the transform domain serves as the reference to all the pixels within a block, including the pixels along the block boundaries. In a large flat area, the difference of DC coefficients from adjacent blocks can cause severe blocking effects which are not limited on the block boundary area. To solve this problem, a DC calibration algorithm is proposed in [3]. But their approach has to change the JPEG encode scheme, thus it can not be used in existing JPEG standard.

To keep the post-processor compatible with the universal accepted JPEG standard, we choose mid-point displacement interpolation as our tool to remove the blocking effect appeared in a large gradual change region. Before we do mid-point displacement interpolation, we have to specify the areas to be processed. The rule we set is: if the four adjacent blocks connected each other all have be classified as blocking block from the image segmentation step, then these four blocks are combined into a macro block.

Next, we apply mid-point displacement interpolation on the macro blocks. For a specific macro block under concern, we choose a center pixel from each of the four blocks, say at the location $(4,4)$, as our starting point. These center pixels are denoted as A, B, C and D in Fig. 4, respectively. Then the pixel at location E which has equal distance with A, B, C and D will be interpolated. The new pixel value at location E is generated by taking an average of the surrounding pixels A, B, C and D. The mid-point displacement algorithm is a recursive algorithm. On the second stage, we will

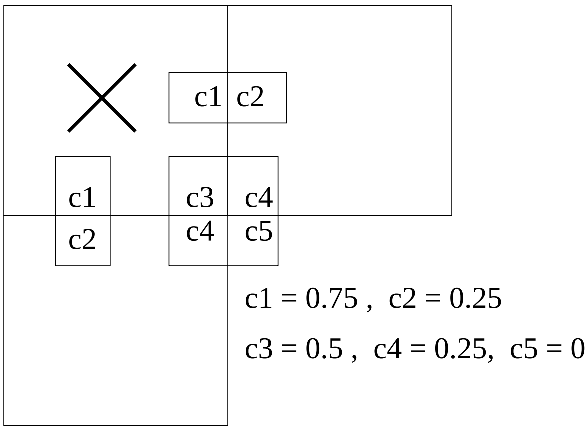

Figure 3. The low-pass filter for the pixels at the block boundary. X is the block being processed

fill in the pixels at the location F, G, H and I. The pixel value at these locations has two choices. Let the pixel at location G be an example. It is the center of pixel A, E, C and J. And the pixel J does not belong to the macro block under concern. If the block which the pixel J "sits" in is a blocking block, then the pixel value of G will be the average of pixels A, E, C, and J, otherwise, the pixel G keeps its original value. The same rule is valid for the pixels F, H and I. On the next stage, all the pixels at the location "*" will be interpolated. This process continues until all the pixels have been filled.

Up to now, the blocking artifacts have been removed. We will move to ringing artifacts reduction section.

2.3. Removal of Ringing Artifact

Since the ringing blocks have been found, the next step is to detect the edges in the image. The necessity of edge detection is to conserve the edges while applying an edge-adaptive lowpass filter along the edges for ringing reduction.

There are many gradient operators available for edge detection. Sobel operator is our choice because it is simple and easy to be implemented in digital hardware. For Sobel edge detection, the pixel location (m, n) is declared an edge location if $g_{H1}(m, n)$ or $g_{H2}(m, n)$ is greater than a chosen threshold t, where $g_{H1}(m, n)$ and $g_{H2}(m, n)$ are the outputs of the filters whose impulse functions are the Sobel masks. The Sobel masks $H1$ and $H2$ are defined as:

$$H1 = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad (5)$$

$$H2 = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \quad (6)$$

The threshold t is determined by experiments in order to obtain the least mean -square-error (MSE) of the post-processed image. We found the threshold t equal to 15 is the best one for the "Lena" picture. For the other test images, the best choice of t is also around 15. If we don't want to change the threshold while the image changes, we can set $t = 15$ as our default value. Although we may not get the best result, the actual result is very close to it.

From the ringing block identification step above, we know which blocks of the image exist ringing artifacts. Thus we can work only on these blocks. For each ringing block, it is divided into several small regions separated by the edges.

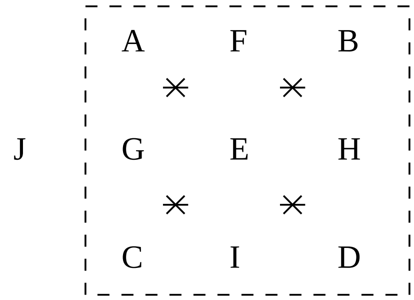

Figure 4. The Mid-point Displacement Interpolation

Then a simple low-pass filter which takes average value of the pixels in the region applies each region individually. Since this low-pass filter does not touch the edge pixels, the edge will not be blurred by the filter.

2.4. Fidelity Constraint

With the post-processing steps above, blocking and ringing artifacts have been minimized. But both blocking and ringing artifacts reduction have been done in the spatial domain. The transform domain constraint condition has not been considered. According to quantization theory, given quantization table (QT) and quantized DCT coefficients, the ranges of the original image's unquantized DCT coefficients have been confined. If the decompressed image is perfectly recovered and free of blocking and ringing artifacts, its DCT coefficients should be the same with the original received DCT coefficients. This condition is often used in convex projection image recovery algorithms [8]. We will use this constraint to improve the bitstream consistency.

Let us start with blocking block constraint. After mid-point displacement interpolation, we perform DCT and quantization to these smoothed blocks. If the resulting quantized DCT coefficients are within received values plus or minus quantization bin value, then the recovered DCT coefficients will be used. Otherwise, if an individual resulting quantized DCT coefficient is beyond the range, it will be replaced by the maximum or minimum value allowed in that range. This step can overcome over-smoothing in the blocking blocks. Similarly, we perform the same constraint to the ringing blocks. By doing this, we can avoid over-smoothing the ringing blocks due to the false regions caused by incorrect edge detection.

3. SIMULATION AND COMPARISON

In this section, the performance of the proposed postprocessor is evaluated both objectively and subjectively by computer simulation. Two performance measures will be used in this paper. One is root mean-squared error (RMSE), the other is peak signal-to-noise ratio (PSNR). PSNR in decibels (dB) is computed as

$$PSNR = 20 \log_{10} \frac{255}{RMSE}$$

where RMSE is defined as

$$RMSE = \sqrt{\frac{1}{NM} \sum_{i=1}^{N} \sum_{j=1}^{M} [f(i,j) - \hat{f}(i,j)]^2}$$

and N and M are the width and height, respectively, of the images in pixels, f is the original image, and $\hat{f}$ is the reconstructed image.

The two 512 × 512-pixel test images, "Lena" and "Peppers", are used in simulation experiments. They are both encoded at 0.25 bpp by using JPEG baseline algorithm and JPEG default quantization table. Then the proposed postprocessor is applied to these JPEG encoded images. The performance measures in RMSE and PSNR are shown in Table 1. As expected, our proposed postprocessor achieved 0.6 dB improvement of PSNR over the standard JPEG image at 0.25 bpp. Fig. 5 and Fig. 6 show the detail comparison between standard JPEG encoded "Lena" and our reconstructed one. The visual inspection of these two indicates that the proposed algorithm achieved vast improvement in terms of perceptible blocking and ringing artifacts.

Table 1. The Performance Comparison Between the Standard JPEG Encoded Images and Postprocessed Images at 0.25 bpp

image	type	RMSE	PSNR
Lena	JPEG	7.7003	30.40
	Proposed	7.1646	31.03
Peppers	JPEG	7.9456	30.13
	Proposed	7.3646	30.79

4. CONCLUSIONS AND FUTURE WORKS

We have presented a novel postprocessor to remove blocking and ringing artifacts for block transform encoded images. Both objective and subjective results showed the superiority of the new method. The proposed technique can be applied to video such as MPEG. For practical applications, a real-time implementation for the proposed postprocessor is necessary and will be our future work.

Figure 5. "Lena" - Before Post Processing - 0.25bpp

Figure 6. "Lena" - After Post Processing - 0.25bpp

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