MODEL-BASED SMOOTHING FOR REDUCING ARTIFACTS IN COMPRESSED IMAGES

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ABSTRACT

Blocking artifacts often appear in compressed images coded by the block discrete cosine transform. This paper presents a smoothing method for reducing those artifacts. The method is based on adjusting pixel intensities of a blocky image to values determined by a smooth model image. Certain points in the blocky image are selected to construct a triangular mesh. The mesh forms the model image. The adjusted image is further subject to a narrow quantization constraint. The method produces superior images in terms of subjective quality and objective quality when compared to existing methods. It is fast since no iterations are required.

1. INTRODUCTION

Coding techniques based on the block discrete cosine transform (BDCT) are widely used for image and video compression. The main concept of the techniques is to partition an image into blocks. Then, each block is transformed separately. Finally, transform coefficients are quantized and coded. The popular JPEG and MPEG compression standards are based on the BDCT.

A major drawback of BDCT-based compression techniques is the generation of blocking artifacts, especially at a high compression ratio. Since each block is transformed and quantized independently, a coded image often presents discontinuities between blocks. They appear as blocking artifacts (see, e.g., the top-left image of Figure 4). Artifacts are more visible in a low activity region than in a high activity region. They may appear as staircases.

Blocking artifacts can be reduced by applying the theory of projection onto convex sets (POCS) [1][2][3][4][5]. The idea is to impose certain constraints to make a decoded image approach its original artifact-free form. Other deblocking techniques include low pass filtering [6] and wavelet transforms [7]. POCS-based deblocking methods often produce better images in terms of subjective and objective quality measures, when compared to other methods. However, they have been critised for being slow since they are iterative in nature.

This paper presents a model-based smoothing method for reducing blocking artifacts. The concept is to adjust pixel intensities in a block-coded image to values which are determined by a smooth image model. The model is built by a triangulation on certain points of the blocky image. Then the modified image is further subject to a narrow quantization constraint. The method does not require iterations. Thus it is fast compared to POCS-based methods. Deblocking results obtained from the method are superior to those obtained from POCS-based methods.

2. MODEL-BASED SMOOTHING

The proposed method is non-iterative. It consists of two steps. In the first step, abrupt changes between blocks in a blocky image are reduced using a smooth model image. In the second step, pixel intensities are further adjusted by applying a narrow quantization constraint. Then an inverse BDCT is applied to produce the final image.

2.1. Model Image

An $M \times N$ digital image can be represented by an $(M \times N) \times 1$ vector

$$\mathbf{f} = [I_1, I_2, ..., I_{MN}]^t, \tag{1}$$

in the Euclidean space $\Re^{MN}$, where t denotes the matrix transpose and I_i $(i = 1, 2, ..., MN)$ is the intensity of a pixel i. Let $\mathbf{f_0}$ and $\tilde{\mathbf{f}}$ be a coded image and its corresponding image before compression, respectively. A triangular mesh simulating $\tilde{\mathbf{f}}$ is constructed based on the data obtained from $\mathbf{f_0}$. The aim is to reduce the intensity difference between blocks in $\mathbf{f_0}$.

The triangulation technique is often used for mesh generation [8]. A triangle in a 3D space can be arbitrarily oriented, and hence can be used to represent a small part of

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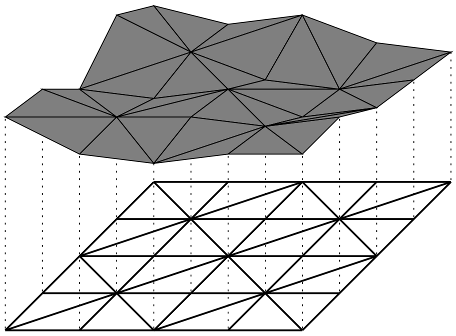

Fig. 1. A digital image is simulated by a triangular mesh.

an arbitrarily oriented surface. A digital image before compression is simulated by a triangular mesh in this case as the pixels in the image can be regarded as the sample points of a 3D surface (Figure 1). It is observed that a triangular mesh is continuous at each triangle edge. In other words, there is no abrupt change from one side of a triangle edge to the other. This property can be used to reduce intensity variations between blocks in a block coded image.

There are various triangulation schemes. Since an image is compressed based on a block structure, it is convenient to triangulate each block separately. In the JPEG standard, an image is divided into 8×8 blocks. It is assumed, in this case, that a block consists of 8×8 pixels. A block is divided into a set of triangles by selecting certain points in the block as constructing sites (Figure 2). There are five sites on each block edge. They are shared by the triangles of two adjacent blocks so that a mesh can be generated. The number of triangles in a block is determined by the activity of the block. A high activity block requires more triangles to simulate than a low activity block. Such an arrangement is made to reduce errors in mesh generation. A high activity block usually contains more image details than a low activity block. Hence a large number of small triangles are required to simulate it. On the other hand, a low activity block often lies on a flat region, and hence needs a small number of large triangles to represent. Let γ be the activity index of a block. The block is divided into 14 triangles if $\gamma < \gamma_1$, 16 triangles if $\gamma_1 \leq \gamma < \gamma_2$, 32 triangles if $\gamma_2 \leq \gamma < \gamma_3$, or 64 triangles if $\gamma \geq \gamma_3$, where γ_1, γ_2, and γ_3 are thresholding values. Figure 2 shows the triangulation scheme. It can be proven that this is a Delaunay triangulation where the circumcircle of each triangle does not contain in its interior any other vertex of the triangulation [8]. The Delaunay triangulation is suitable for mesh generation since it maximizes the minimum angle over all other triangulations.

The above triangulation scheme has a number of features. First, each block has 16 evenly distributed sites on its boundary. This arrangement facilitates the mesh construction since each site on a block edge is shared by triangles on both sides of the edge. Second, the sites inside a block are also evenly distributed. The higher the activity of a block, the larger the number of its internal sites. This feature ensures that a mesh thus constructed is adaptive to the local block activity. Third, a block has no site in its interior if it is divided into 14 triangles. A triangle near a corner of the block connects two edges of the block. The triangle is helpful for reducing the intensity difference between one block edge and the triangle interior, and between the triangle interior and the other block edge, and hence is useful for reducing staircase artifacts.

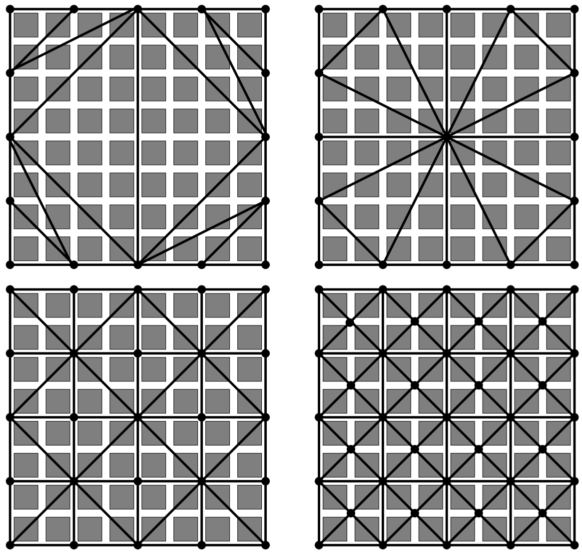

Fig. 2. An 8×8 block is divided into (top-left) 14 triangles if $\gamma < \gamma_1$, (top-right) 16 triangles if $\gamma_1 \leq \gamma < \gamma_2$, (bottom-left) 32 triangles if $\gamma_2 \leq \gamma < \gamma_3$, (bottom-right) 64 triangles if $\gamma \geq \gamma_3$. Construction sites are shown as black dots. A grey square represents a pixel.

In constructing a triangular mesh, the intensity of a site is determined by the intensities of its surrounding pixels. A site is always located at the center of 4 mutually adjacent pixels. The intensity of the site is the average intensity of its 4 surrounding pixels. The intensities of other points in a block are approximated by the triangular mesh.

The AC components of the quantized DCT coefficients of a block determine the activity index γ ($\gamma \geq 0$) of the block. Let $B(u, v)$ ($u, v = 0, 1, ...7$) be a DCT coefficient of a block. γ is defined as

$$\gamma = \sum_{u=0}^{7} \sum_{v=0}^{7} B^2(u, v) - B^2(0, 0). \qquad (2)$$

The thresholding values γ_1, γ_2 and γ_3 are determined empirically. In this case, $\gamma_1 = 5$, $\gamma_2 = 20$ and $\gamma_3 = 80$.

After a model image is formed, the associated blocky image is modified by changing its pixel intensities to the corresponding values in the model image.

2.2. Narrow Quantization Constraint

After the smoothing operation, a coded image may be blurred. A narrow quantization constraint is applied in this case to recover image details.

A BDCT coefficient before quantization should be within a certain interval determined by the quantization step [1]. The corresponding quantized BDCT coefficient is the midpoint of the interval. Park and Kim apply a narrow quantization constraint in their deblocking method to achieve improved peak signal-to-noise ratios in resulting images [3]. However, the method is lack of adaptability since a global scaling coefficient is used to determine the bound of each BDCT coefficient. An adaptive quantization constraint is proposed in this case. The local block activity is taken into account in deciding scaling coefficients.

Let $\mathbf{f} \in \Re^{MN}$ and $\mathbf{f_0} \in \Re^{MN}$ be a processed image, which approximates an image before compression, and the corresponding BDCT coded image, respectively. Each BDCT coefficient $(T\mathbf{f})_i$ $(i = 1, 2, ..., MN)$, where T denotes the BDCT, is subject to the following quantization constraint,

$$F_i^0 - \mu_i \Delta_i \leq (T\mathbf{f})_i \leq F_i^0 + \nu_i \Delta_i, \tag{3}$$

where $F_i^0 = (T\mathbf{f_0})_i$, $\mu_i \in [0, 1]$ and $\nu_i \in [0, 1]$ are scaling coefficients, and Δ_i is half of the quantization step of $(T\mathbf{f})_i$.

If $\mu_i = \nu_i = 1$, Equation (3) represents the standard quantization constraint [1][2]. If $\mu_i = \nu_i = 0$, the constraint allows only the BDCT compressed image $\mathbf{f_0}$. If $0 < \mu_i, \nu_i < 1$, the constraint is a narrow quantization constraint since each BDCT coefficient is allowed a narrow range when compared to the standard quantization constraint.

The scaling coefficient μ_i or ν_i is selected based on the local block activity. It is large for a low activity block to allow a large amount of adjustment in pixel intensities to reduce the difference between two sides of a block edge. It is small for a high activity block to allow a small amount of adjustment to avoid excessively blurring. The scaling coefficients are determined empirically. For a block divided into 14 triangles, $\mu_i = \nu_i = 1$. For a block divided into 16 triangles, $\mu_i = \nu_i = 0.8$. For a block divided into 32 or 64 triangles, $\mu_i = \nu_i = 0.5$.

The application of the constraint is straightforward. A BDCT coefficient in a smoothed image is assigned the value of its nearest bound if it lies outside the bound.

3. EXPERIMENT RESULTS

Various JPEG encoded images have been tested using the proposed method. Figure 3 shows a typical 512×512 test image, Lena. Four POCS-based deblocking methods, namely Zakhor's method [1], Yang *et al.*'s method [2], Park and Kim's method [3], and Jeong *et al.*'s method [4] are implemented for comparison.

Fig. 3. A typical 512×512 image - Lena.

Figure 4 shows a part of an enlarged version of Lena coded at 0.188 bits per pixel (bpp), and deblocking results using different methods. It can be seen that the proposed method produces a significantly improved image when compared to the block coded image. The blocking artifacts in the former have been greatly reduced. Furthermore, the result of the method has the best visual quality among those obtained from five competing methods. Artifacts in the result obtained from Zakhor's method have been reduced. However, the image becomes blurred. Results obtained from other three methods still contain visible artifacts. The proposed method is capable of reducing blocking artifacts while preserving image details.

The objective quality of a processed image $\mathbf{f}$ ($\mathbf{f} \in \Re^{MN}$) is measured by its peak signal-to-noise ratio (PSNR) defined in decibels by

$$PSNR = 10 \log_{10} \left[\frac{MN \times 255^2}{||\mathbf{f} - \tilde{\mathbf{f}}||^2} \right], \tag{4}$$

where $\tilde{\mathbf{f}} \in \Re^{MN}$ is the original image before compression. The higher the PSNR, the smaller the difference $||\mathbf{f} - \tilde{\mathbf{f}}||$ between the processed image and its original.

Figure 5 shows the PSNR values of the deblocking results of the JPEG-encoded Lena image using different methods. The image is coded at different bit rates. It can be seen that the deblocking results obtained from the proposed method have the highest PSNRs among those obtained from five competing methods. In other words, the method produces better images than other methods in terms of subjective quality measured by the PSNR.

4. CONCLUSION

Model-based smoothing is considered for reducing blocking artifacts in BDCT-coded images in this paper. The De-

Fig. 4. (Top-left) JPEG compressed Lena. (Top-right) Deblocking result of Zakhor's method. (Middle-left) Yang *et al.*'s result. (Middle-right) Park and Kim's results. (Bottom-left) Jeong *et al.*'s results. (Bottom-right) Result of the proposed method.

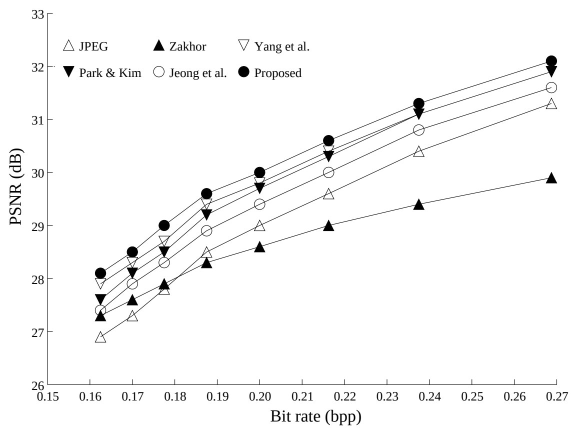

Fig. 5. A comparison of deblocking results in terms of PSNR using different methods.

launay triangulation is applied to build model images. The triangulation is adaptive to the local block activity. The higher the local activity, the larger the number of triangles to represent the underlying block. Triangles in low activity blocks are specially arranged to reduce staircase artifacts. A narrow quantization constraint is applied to recover image details. The constraint is also adaptive to the local activity. The higher the local activity, the smaller the scaling coefficients. The proposed method produces better quality images in terms of subjective and objective measures when compared to POCS-based deblocking methods. It is a non-iterative method. Thus, it is fast compared to iterative methods, such as POCS-based methods. The method can be used to reduce blocking artifacts in compressed video sequences. It is also suitable for other real-time applications.

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