BLOCKINESS DETECTION IN COMPRESSED DATA.

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ABSTRACT

A novel frequency domain technique for image blocking artifact detection is presented in this paper. The algorithm detects the regions of the image which present visible blocking artifacts. This detection is performed in the frequency domain and uses the estimated relative quantization error calculated when the DCT coefficients are modeled by a Laplacian probability function. Experimental results illustrating the performance of the proposed method are presented and evaluated.

1. INTRODUCTION

The block based discrete cosine transform (B-DCT) scheme is a fundamental component of many image and video compression standards including JPEG [1], H.263 [2], MPEG-1, MPEG-2, MPEG-4 [3] and others, used in a wide range of applications. The B-DCT scheme takes advantage of the local spatial correlation property of the images by dividing the image into 8×8 blocks of pixels, transforming each block from the spatial domain to the frequency domain using the discrete cosine transform (DCT) and quantizing the DCT coefficients. Since blocks of pixels are treated as single entities and coded separately, correlation among spatially adjacent blocks is not taken into account in coding, which results in block boundaries being visible when the decoded image is reconstructed. For example, a smooth change of luminance across a border can result in a step in the decoded image if neighboring samples fall into different quantization intervals. Such so-called "blocking" artifacts, are often very disturbing, especially when the transform coefficients are subject to coarse quantization.

In this paper a new method is proposed for the detection of the blocking effect in the B-DCT. This method is applied only on the compressed data. Blocks which show blocking artifacts with the neighboring blocks are detected. This detection is applied in the subband-like representation of the DCT coefficients produced when DCT transform is assumed to follow Laplacian probability model (hereafter, Laplacian corrected DCT coefficients). Specifically, the presence of visual blocking artifacts of the B-DCT reconstructed image is inferred from data in the frequency domain, when the relative difference of two neighboring Laplacian corrected DCT coefficients in the subband-like domain, is greater than a threshold.

The rest of this paper is organized as follows: Section 2 describes the mathematical analysis underlying the concept of blocking artifact detection in the subband-like transform domain, under the assumption that the DCT transform follows a Laplacian probability density function. Experimental results given in Section 3 evaluate visually and quantitatively the performance of the proposed methods. Finally, conclusions and future work are drawn in Section 4.

2. DETECTION OF BLOCKING ARTIFACTS USING THE DCT LAPLACIAN MODEL IN THE SUBBAND-LIKE DOMAIN

In the classical B-DCT formulation, the input image is first divided into 8×8 blocks, and the two dimensional DCT of each block is determined. The two dimensional DCT can be obtained by performing a one dimensional DCT on the columns and a one dimensional DCT on the rows. The DCT coefficients of the spatial block $B_{i,j}$ are then determined by the following formula:

$$F_{ij}^D(u,v) = C(u)C(v)\times$$

$$[\sum_{n=0}^{7}\sum_{m=0}^{7} f_{ij}(n,m)\cos\frac{(2n+1)u\pi}{16}\cos\frac{(2m+1)v\pi}{16}], \quad (1)$$

$$u,\ v = 0,\ldots,7,\ \ i = 0,\ldots,\frac{N}{8}-1,\ \ j = 0,\ldots,\frac{M}{8}-1,$$

where $F_{ij}^D(u,v)$ are the DCT coefficients of the $B_{i,j}$ block, $f_{ij}(n,m)$ is the luminance value of the pixel (n,m) of the $B_{i,j}$ block, $N \times M$ are the dimensions of the image, and

$$C(u) = \begin{cases} \frac{1}{\sqrt{2}} & \text{if} \quad u = 0 \\ 1 & \text{if} \quad u \neq 0 \end{cases} . \quad (2)$$

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The transformed output from the 2-D DCT is ordered so that the DC coefficient $F_{ij}^D(0,0)$, is in the upper left corner and the higher frequency coefficients follow, depending on their distance from the DC coefficient. The higher vertical frequencies are represented by higher row numbers and higher horizontal frequencies are represented by higher column numbers.

A typical quantization-reconstruction process of the DCT coefficients as described in JPEG [1], is given by:

$$F_{ij}^Q(u,v) = round(\frac{F_{ij}^D(u,v)}{Q_(u,v)}) \quad (3)$$

$$F_{ij}^R(u,v) = F_{ij}^Q(u,v)Q(u,v) \quad (4)$$

where $Q(u,v)$ indicates the quantization width bin for the given coefficient, $F_{ij}^Q(u,v)$ indicates the bin index in which the coefficient $F_{ij}^D(u,v)$ falls and $F_{ij}^R(u,v)$ represents the reconstructed quantized coefficient. Then, the reconstructed pixel intensity is obtained from the inverse DCT.

DCT coefficients with the same frequency index (u,v) from all DCT transformed blocks can be scanned and grouped together, starting from the DC coefficients ($u=0, \;\; v=0$). Thus, transforming an image with an 8×8 2-D DCT can be seen to produce hierarchical data equivalent to those produced by a subband transform of 64 frequency bands.

We shall assume that for typical input image statistics, the DCT coefficients may be reasonably modeled by a Laplacian probability density function (pdf) as [4]:

$$f(x) = \frac{a}{2}e^{-a|x|} \quad (5)$$

which is a zero-mean pdf with variance:

$$\sigma^2 = 2a^2 \quad (6)$$

If the Laplacian-modeled variable is quantized using uniform step sizes, the only information available to the receiver is that the original DCT coefficient is in the interval:

$$\gamma - t \le F_{ij}^D(u,v) \le \gamma + t, \quad (7)$$

where $\gamma = F_{ij}^Q(u,v)Q(u,v)$ and $t = Q(u,v)/2$. The trivial solution suggested in JPEG is to reconstruct the coefficient in the center of the interval as $F_{ij}^R(u,v) = \gamma$, which simplifies implementation. The optimal reconstruction (minimum mean squared error) lies in the centroid of the distribution for the interval $(\gamma - t, \gamma + t)$, thus, under the assumption of Laplacian statistics [5]:

$$\gamma' = \frac{\int_{\gamma-t}^{\gamma+t} \lambda f(\lambda) d\lambda}{\int_{\gamma-t}^{\gamma+t} f(\lambda) d\lambda} = \gamma + \frac{1}{a} - t \, \coth(at) \quad (8)$$

Note that this implies a bias δ toward the origin:

$$\delta = \gamma - \gamma' = t \, \coth(at) - \frac{1}{a}. \quad (9)$$

For different coefficients we have different step sizes and variances [5]. Therefore, considering the DCT coefficient of block $B_{i,j}$ at frequency (u,v), we have quantization step size $Q(u,v)$ and variance $\sigma_{ij}^2(u,v)$. Then, the bias δ_{ij}^{uv} toward the origin can be found from (9) and (7):

$$\delta_{ij}^{uv} = \frac{Q(u,v)}{2} \coth(\frac{a_{ij}(u,v)Q(u,v)}{2}) - \frac{1}{a_{ij}(u,v)} \quad (10)$$

Given the coefficient variances, we can estimate the a parameters using (6), thus $a_{ij}(u,v) = \sqrt{2}/\sigma_{ij}(u,v)$. The variances can be easily estimated by $\sigma_{ij}^2(u,v) = [F_{ij}^R(u,v)]^2$ [6]. Therefore, we can use (9) to precalculate all δ_{ij}^{uv} so as to obtain the optimal estimation $\hat{F}_{ij}^R(u,v)$ of the reconstructed DCT coefficient:

$$\begin{aligned} \hat{F}_{ij}^R(u,v) &= F_{ij}^R(u,v) - sign[F_{ij}^Q(u,v)]\delta_{ij}^{uv} = \\ &= F_{ij}^Q(u,v)Q(u,v) - sign[F_{ij}^Q(u,v)]\delta_{ij}^{uv} \end{aligned} \quad (11)$$

where the $sign$ function is appropriately used to handle both positive and negative values and $sign[0] = 0$.

Let us now define the relative theoretical quantization error e_{ij}^{uv} for coefficient $F_{ij}^Q(u,v)$ by:

$$e_{ij}^{uv} = \frac{\hat{F}_{ij}^R(u,v) - F_{ij}^R(u,v)}{F_{ij}^R(u,v)} \quad (12)$$

We next focus on the difference $|e_{ij}^{uv} - e_{kl}^{uv}|$ between the B_{ij} and B_{kl} blocks. Occurrences of large values of this difference indicate that very different levels were used to quantize the B_{ij} and B_{kl} blocks, producing a blocking artifact between these blocks. Thus, we shall infer the presence of an artifact between blocks B_{ij} and B_{kl} if :

$$|e_{ij}^{uv} - e_{kl}^{uv}| > T_{ijkl}^{uv} \quad (13)$$

where T_{ijkl}^{uv} is an adaptive threshold defined by:

$$T_{ijkl}^{uv} = \frac{\hat{F}_{ij}^R(u,v) - \hat{F}_{kl}^R(u,v)}{F_{ij}^R(u,v) - F_{kl}^R(u,v)} \quad (14)$$

For a given compressed image, the detection criterion is applied on each coefficient in all of the 64 bands of the DCT subband-like domain, in order to locate the most disturbing blocking artifacts. More specifically, for each band in the subband-like domain, we scan the coefficients vertically, horizontally and diagonally, and apply criterion (13). We assume that a blocking artifact between the (i,j) block and the neighboring (k,l) block is disturbing when (13) is satisfied for more than two frequencies in the subband-like domain, e.g. (u,v) and (q,r) frequencies. Thus:

$$\begin{aligned} &\text{Artifact between neighboring blocks } B_{ij} \text{ and } B_{kl} \\ &\text{if } \exists \text{ frequencies } (u,v),(q,r) \text{ that} \\ &|e_{ij}^{uv} - e_{kl}^{uv}| > T_{ijkl}^{uv} \text{ and } |e_{ij}^{qr} - e_{kl}^{qr}| > T_{ijkl}^{qr} \end{aligned} \quad (15)$$

This criterion was tested in a large number of pictures and was found to be very efficient in detecting the most disturbing blocking artifacts.

3. EXPERIMENTAL RESULTS

In this section, simulation results demonstrating the performance of the proposed technique are presented. For this purpose, several images of different characteristics were chosen and compressed using a JPEG and MPEG-1 intra-picture. The same algorithm can be also applied for the case of MPEG inter-coding with no extra modifications.

The blocking artifact detection algorithm, presented in Section 2, was applied to the test images, in order to locate the blocks affected by artifacts in a JPEG coded image. Figs. 1 - 3 show the disturbing blocking artifacts (indicated with a white pixel value) pointed out by the criterion (15) in the JPEG coded images at three different bit rates for the images of "Lenna", "Peppers" and "Claire". In Figs. 1 and 2, magnified portions of the "Lenna" and "Peppers" images are shown, in order to better illustrate the detection of the blocking artifacts.

4. CONCLUSIONS AND FUTURE WORK

When images are highly compressed using B-DCT transforms, the decompressed images contains bothersome blocking artifacts. This paper presented a novel algorithm applied entirely in the compressed domain, in order to detect these blocking artifacts. In our approach, the Laplacian statistical model is adopted for the DCT coefficients and a better estimation of the DCT reconstructed coefficients is produced, in order to calculate the relative theoretical quantization error. This error is used for the efficient detection of blocking artifacts of coded images. After detecting the blockiness, effective algorithms for blockiness removal must be designed and implemented in order to achieve the improvement of the subjective picture quality. Experimental evaluation of the performance of the proposed technique showed its ability to detect blocking artifacts effectively.

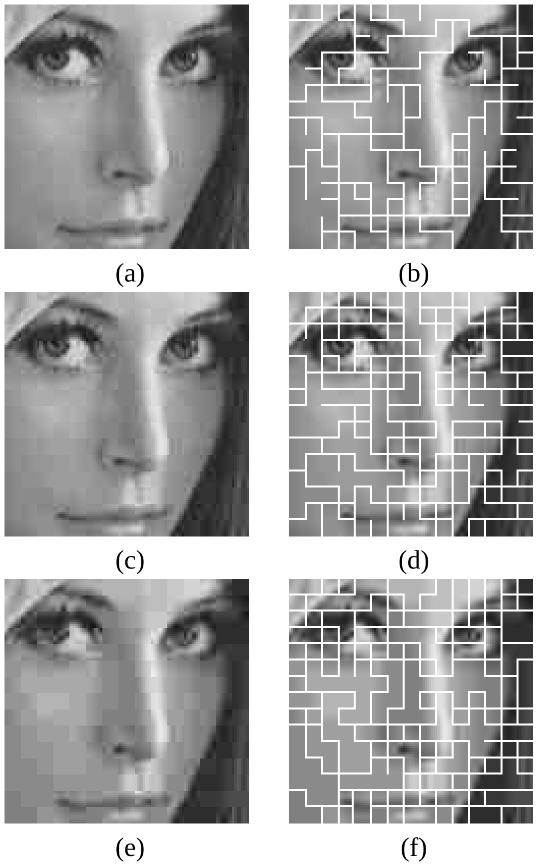

Fig. 1. (a) A portion of JPEG coded "Lenna" image at 0.4096 bpp, (b) Detection of blocking artifacts at 0.4096 bpp, (c) A portion of JPEG coded "Lenna" image at 0.2989 bpp, (d) Detection of blocking artifacts at 0.2989 bpp, (e) A portion of JPEG coded "Lenna" image at 0.1942 bpp, (f) Detection of blocking artifacts at 0.1942 bpp.

5. REFERENCES

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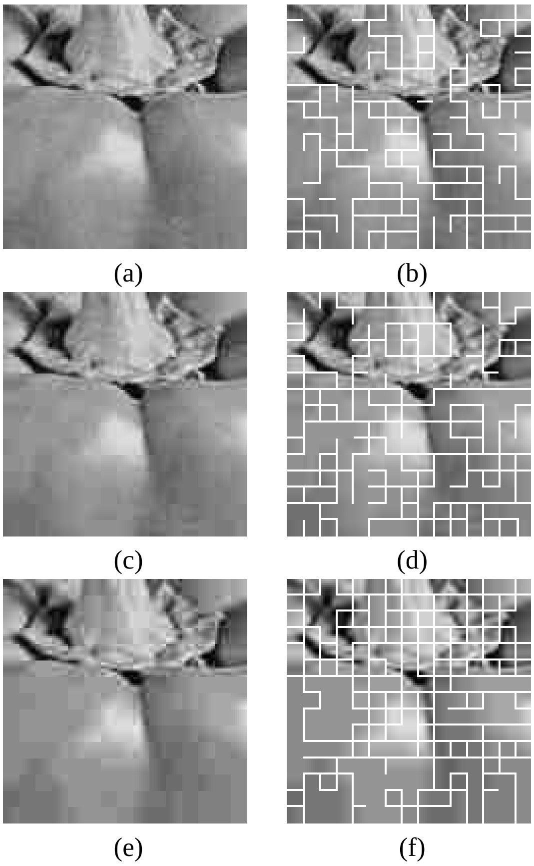

Fig. 2. (a) A portion of JPEG coded "Peppers" image at 0.4211 bpp, (b) Detection of blocking artifacts at 0.4211 bpp, (c) A portion of JPEG coded "Peppers" image at 0.3137 bpp, (d) Detection of blocking artifacts at 0.3137 bpp, (e) A portion of JPEG coded "Peppers" image at 0.1989 bpp, (f) Detection of blocking artifacts at 0.1989 bpp.

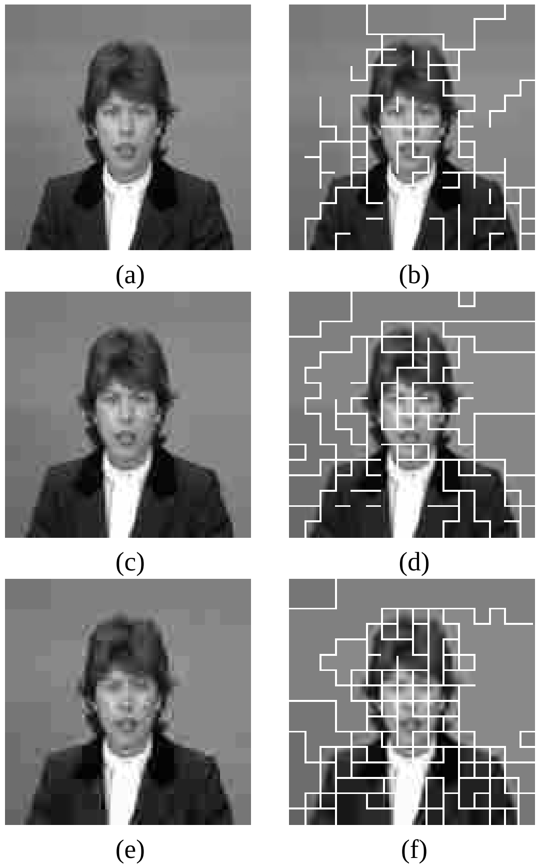

Fig. 3. (a) The JPEG coded "Claire" image at 0.4907 bpp, (b) Detection of blocking artifacts at 0.4907 bpp, (c) The JPEG coded "Claire" image at 0.3779 bpp, (d) Detection of blocking artifacts at 0.3779 bpp, (e) The JPEG coded "Claire" image at 0.2968 bpp, (f) Detection of blocking artifacts at 0.2968 bpp.

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