DCT-DOMAIN BLIND MEASUREMENT OF BLOCKING ARTIFACTS IN DCT-CODED IMAGES

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ABSTRACT

A method for DCT-domain blind measurement of blocking artifacts is proposed in this paper. By constituting a new block across any two adjacent blocks, the blocking artifact is modeled as a 2-D step function. A fast DCT-domain algorithm has been derived to constitute the new block and extract all parameters needed. Then an HVS based measurement of blocking artifacts is conducted. Experimental results have shown the effectiveness and stability of our method. The proposed technique can be used for online image/video quality monitoring and control in applications of DCT-domain image/video processing [1, 2].

1. INTRODUCTION

Digital image/video is becoming widely available as JPEG, MPEG or H.26x bit-streams. All these standard are based on Discrete Cosine Transform (DCT) technology. To process these bit-streams efficiently and quickly, many image/video processing algorithms which can be applied directly to the DCT-domain have been developed to avoid the process of complete decompression and compression [1, 2]. While most of these techniques were proven to be effective to accelerate the processing, they did not mention how to assess the quality of the image/video before or after processing. Since only the DCT coefficients are available in DCT-domain image/video processing methods, it would be advantageous to measure the quality of image/video in the DCT-domain. In this paper, we propose a novel DCT-domain algorithm for the blind measurement of blocking artifacts in DCT-coded images by modeling the blocking artifact as a 2-D step function. Compared to other spatial domain algorithms, the DCT-domain algorithm also takes advantage of the sparseness of the DCT coefficients to reduce the compu-

tational complexity significantly, which is important for real-time applications.

2. MODEL OF BLOCKING ARTIFACTS AND ITS IMPLEMENTION

At moderate compression ratios, DCT-based coding supplies excellent reproduction. However, at low bit rates, severe blocking artifacts appear due to the large quantization scale factor, which quantizes most of the DCT coefficients to zeros. Fig.1 shows four enlarged JPEG-coded images Lena at 2 bits/pixel, 1 bit/pixel, 0.5 bits/pixel and 0.2 bits/pixel respectively, from which one can see that the blocking artifacts seriously degrade the visual quality of the coded image at a bit rate of 0.2 bits/pixel. Since the blocking effects in the horizontal and vertical directions generally have no difference in principle, we only consider vertical blocking effects in the following analysis.

2.1. Model of Blocking Artifacts

For natural images, we model each block as a constant block distorted by i.i.d. white noise with zero mean and a small variance [4]. Consider two adjacent 8×8 blocks x_1, x_2 with average values $\overline{a}$ and $\overline{b}$, respectively, where $\overline{a} \neq \overline{b}$. Thus, we can model these two blocks as follows:

$$x_1 = \overline{a} + \varepsilon_{i,j}, \qquad x_2 = \overline{b} + \delta_{i,j}. \qquad (1)$$

where $\varepsilon_{i,j}$ and $\delta_{i,j}$ are modeled as i.i.d. white noise blocks with zero mean. We next form an *overlap block* composed of the bottom half of x_1, and the top half of x_2 to constitute a new 8×8 block x as shown in Fig. 2. Let us define a 2-D step function in the block x as follows:

$$u = \begin{cases} -1/2; & \textit{top half of the block } x. \\ 1/2; & \textit{bottom half of the block } x. \end{cases}$$

Let $S = \overline{b} - \overline{a}$, the new block can be modeled as follows:

$$x = S \bullet u + \zeta_{i,j} + B \tag{2}$$

where $|S|$ represents the amplitude of 2-D step function u, B is the average value in the block x, which can be considered as the local background brightness, and $\zeta_{i,j}$ is a white noise with zero-mean, which can be considered as the local activity around the block edge. The larger the value of $|S|$, the more serious the blocking artifacts should be, provided the background brightness and local activity remain unchanged. So we can measure the blocking artifacts between these two blocks by estimating the value of $|S|$. To make the estimation of $|S|$ more accurate, we let $\overline{a}$ be the average value of the bottom 4 rows of x_1, and $\overline{b}$ be the average value of the top 4 rows of x_2.

2.2. Fast DCT-Domain Implementation

Let X_1, X_2 be the DCT's of x_1, x_2 respectively. First let us define two matrices q_1 and q_2 as follows:

$$q_1 = \begin{bmatrix} O & I_{4\times4} \\ O_{4\times4} & O \end{bmatrix}, \quad q_2 = \begin{bmatrix} O & O_{4\times4} \\ I_{4\times4} & O \end{bmatrix} \tag{3}$$

where $I_{4\times4}$ is an identity matrix, and $O_{4\times4}$ is a zero matrix. Using the linear and distributive properties of DCT [1], the following equation in the DCT-domain can be attained:

$$X = Q_1 X_1 + Q_2 X_2, \tag{4}$$

where X, Q_1, and Q_2 are the DCT's of x, q_1 and q_2 respectively. However, the matrices Q_1 and Q_2 are not sparse, which means that a lot of multiplications may probably be necessary in (4) to obtain X. Closer observation of Q_1 and Q_2 shows that most of the corresponding elements are the same, sometimes with a different sign, which means that their sum $F_+ = Q_1 + Q_2$ and their difference $F_- = Q_1 - Q_2$ are sparser. In fact, about 70 percent of elements in F_+ and 50 percent in F_- are zero. Let $Y_+ = X_1 + X_2$, and $Y_- = X_1 - X_2$. We can use the following relation:

$$\begin{aligned} X &= Q_1 X_1 + Q_2 X_2 \\ &= \frac{1}{2}[(Q_1 + Q_2)(X_1 + X_2) + (Q_1 - Q_2)(X_1 - X_2)] \\ &= \frac{1}{2}(F_+ Y_+ + F_- Y_-). \end{aligned} \tag{5}$$

In (5), more than half of the multiplications will be avoided even if we don't consider the sparseness of the DCT block. From the DCT coefficients in X, we can obtain B and S, defined in (2), as follows:

$$B = X(0,0)/8. \tag{6}$$

$$\begin{aligned} S = [&-Q_2(0,0)Y_-(0,0) + Q_2(1,0)Y_+(1,0) + Q_2(3,0)Y_+(3,0) \\ &+ Q_2(5,0)Y_+(5,0) + Q_2(7,0)Y_+(7,0)]/4. \end{aligned} \tag{7}$$

The above relation uses the following fact:
$$Q_1(0,0) = Q_2(0,0), Q_1(k,0) = -Q_2(k,0); k = 1,3,5,7$$
$$Q_1(k,0) = Q_2(k,0) = 0; k = 2,4,6$$

We treat all AC coefficients in X as local activities, which will be discussed in detail in Section III. Now we can summarize the DCT-domain algorithm as the following steps:

♦ Given two adjacent blocks X_1 and X_2, calculate the sum Y_+ and the difference Y_-;
♦ Constitute the new block using equation (5);
♦ Compute B by (6), and S by (7).

To calculate the horizontal blocking artifacts, we can transpose the whole image and use the same method as described above.

3. HVS BASED MEASUREMENT OF BLOCKING ARTIFACTS

In general, a human observer is the end user of most image information. The measurement of blocking artifacts that is based on human perception should be more appropriate for judging the visibility of blocking artifact [3]. Brightness (luminance) masking and activity (texture) masking are the two most significant effects with respect to the visual perception of blocking artifacts. We assume that the total activity of a given block is simply the sum of the activities due to all its spatial frequencies, and the DCT coefficient is the amplitude of the expected component [3]. Masking also depends on the relative orientation [3]. Since blocking artifacts have two particular directions in the image, vertical and horizontal, an edge distortion will be more masked if the activity in the background has the same orientation. To account for this property, we define two distinct oriented activities, vertical activity A_v and horizontal activity A_h, as follows:

$$\begin{aligned} A_v &= \sum_{v=1}^{7} v \sum_{u=0}^{7} |X(u,v)| \\ A_h &= \sum_{u=1}^{7} u \sum_{v=0}^{7} |X(u,v)| \end{aligned} \tag{8}$$

For vertical blocking artifacts, the vertical activity will be dominant, which leads to

$$A_{total}^{v} = A_v + \alpha A_h \tag{9a}$$

Similarly, for the horizontal artifacts, the final activity may be written as

$$A_{total}^{h} = A_h + \alpha A_v \tag{9b}$$

where $\alpha = 0.8$, according to [3].

The masking of artifacts due to activity should vary as a decreasing function of the local activity. Although some more accurate yet complicated models have been advanced [3,5], we propose a simple model given below to facilitate some real-time applications.

$$S_a = \frac{|S|}{1 + A_{total}} \qquad (10)$$

where $|S|$ is the amplitude of 2-D step function in block x (defined in section II), S_a is the visibility of the artifact after activity masking, and A_{total} can be either A^v_{total} or A^v_{total}, depending on the direction of the blocking artifact being considered. The visibility of the blocking artifact also depends on the brightness of the local background [3,5]. To account for this phenomenon, we adopt the model proposed in [5], which is

$$S_b = \frac{S_a}{1 + (\frac{B}{B_0})^r} \qquad (11)$$

where B (defined in section II) is the average value of block x, $B_0 = 150$, and $r = 2$ [5].

To this point, a map of artifact visibility has been computed on the whole image. These values can be used by block artifacts reducing algorithms to adaptively process each block edge according to its local visibility [3, 4]. They also could be combined to have a numerical value predicting the overall image quality as follows:

$$S_t = \sqrt[p]{\frac{1}{N} \sum_{k=1}^{N} (S_b)_k^p} \qquad (12)$$

where N is the total number of inter-block boundaries in the image, S_t is the global measure of the blocking artifacts in the image, and the exponent $p=4$ [3].

4. EXPERIMENTAL RESULTS

We applied our algorithm to the JPEG-coded gray scale images, "Lena" and "Mandrill", with different bit rates. The results are shown in Fig. 3. It can be seen that the value of S_t increases noticeably for bit rates lower than 0.5 bits/pixel, and is almost zero for bit rates higher than 1 bits/pixel. This is coincident with visual perception result (shown in Fig. 1). In Fig. 1, the images coded at 2 bits/pixel and 1bit/pixel have no obvious blocking artifacts, the image coded at 0.5 bits/pixel suffers slightly from blocking artifacts, and the one coded at 0.2 bits/pixel has serious blocking artifacts. Similar results have also been reported in [3, 6], where different methods for blind measurement of blocking artifacts were employed. Further measurement results across different type of images are shown in Table I. (the images can be downloaded from ftp://pepperoni.ece.utexas.edu/pub/). From Table I, we can see the proposed method is quite stable across different images. The measured blocking artifacts monotonically decrease similar to those in the

images "Lena" and "Mandrill" when the bit rate increases, while different images have different degrees of blocking artifacts at the same bit rate.

5. CONCLUSIONS

To objectively assess the degree of blocking artifacts in a compressed image, we proposed a novel DCT-Domain blind measurement of blocking artifacts in DCT-Coded images. The experimental results have shown that our method is effective and stable across different images. The algorithm, implemented in the DCT-domain, can be even faster when the sparseness of the DCT block is taken into account, which makes it very suitable for real-time applications, such as online image quality monitoring and control in applications of DCT-domain image/video processing. Based on the results from our algorithm, some DCT-domain de-blocking techniques can also be derived to mitigate the blocking artifacts if necessary.

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Table I Measuring Results of Blocking Artifacts of JPEG Coded Images

Images	JPEG coded bit rate (bits/pixel)										
	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0
Barbara	19.25	7.915	6.010	2.232	1.519	1.118	0.854	0.783	0.523	0.018	0.013
Pepper	19.39	6.102	3.346	1.794	1.232	0.740	0.634	0.352	0.014	0.011	0.010
Cameraman	25.76	7.457	2.888	2.068	1.727	1.362	0.796	0.628	0.397	0.177	0.009
Irisflower	15.35	6.885	3.426	2.181	1.491	0.892	0.462	0.452	0.235	0.009	0.007
Lab	14.26	5.258	3.061	2.091	1.457	1.118	0.844	0.759	0.566	0.123	0.011
Cane	13.91	5.171	0.613	0.385	0.309	0.023	0.020	0.019	0.018	0.015	0.013
Eggs	7.650	1.034	0.610	0.142	0.031	0.022	0.020	0.018	0.016	0.014	0.013
Plank	5.146	2.161	1.322	0.805	0.490	0.324	0.102	0.100	0.007	0.005	0.004
Eveface	5.408	1.848	0.910	0.431	0.299	0.031	0.014	0.012	0.012	0.011	0.010
Tower	5.061	2.229	1.314	0.660	0.619	0.271	0.010	0.006	0.007	0.004	0.004

(a) 2 bits/pixel   (b) 1 bit/pixel   (c) 0.5 bits/pixel   (d) 0.2 bits/pixel
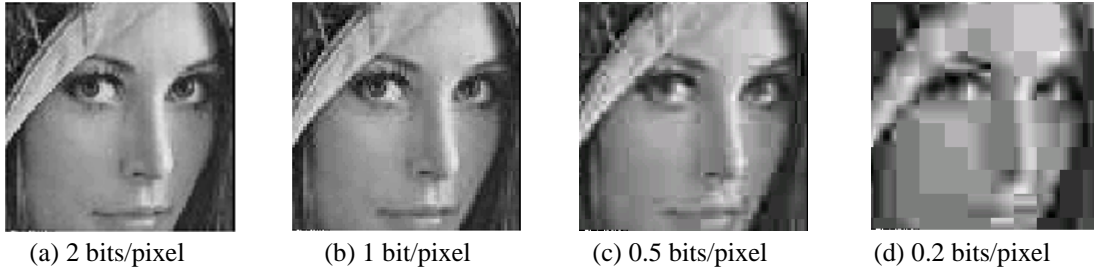
Fig. 1.   JPEG-coded images Lena at different bit rates
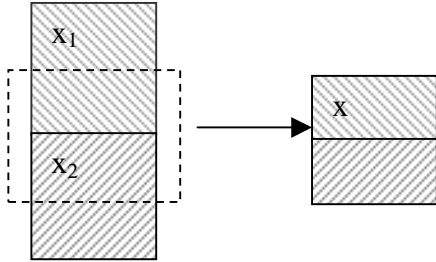

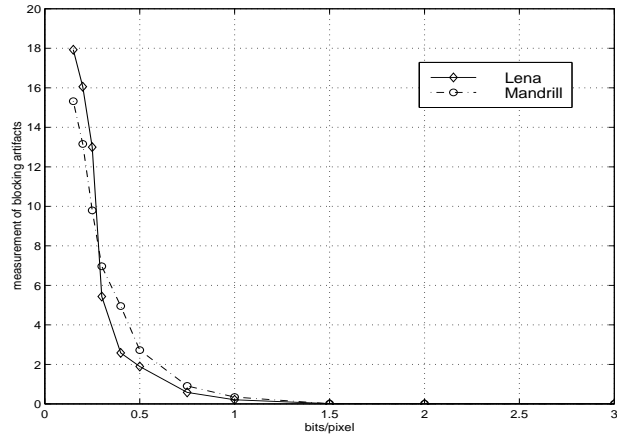Fig. 2.   Method to constitute the new block x

Fig. 3.   Measurement results of blocking arti-
facts in JPEG-coded images