Reduction of Blocking Artifacts in Both Spatial Domain and Transformed Domain

Wing-kuen Ling and P. K. S. Tam

Department of Electronic and Information Engineering
The Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong
Hong Kong Special Administrative Region, China
Tel: (852) 2766-6238, Fax: (852) 2362-8439
bingo@encserver.eie.polyu.edu.hk

Abstract. *In this paper, we propose a bi-domain technique to reduce the blocking artifacts commonly incurred in image processing. Some pixels are sampled in the shifted image block and some high frequency components of the corresponding transformed block are discarded. By solving for the remaining unknown pixel values and the transformed coefficients, a less blocky image is obtained. Simulation results using the Discrete Cosine Transform and the Slant Transform show that the proposed algorithm gives a better quantitative result and image quality than that of the existing methods.*

1. Introduction

Many images are very large in size, and so it typically requires an extensive computation to process a whole image. Hence, dividing an image into a number of small blocks with size *8x8* for processing is very common in practice, such as that employed in the JPEG, MPEG-1/2, H.261/263 standards. However, the block-based coded images suffer from a kind of distortion, called blocking artifacts, especially when the compression ratio is high. There are boundaries among the blocks and these boundaries are very disturbing.

Several techniques have been developed to reduce the blocking artifacts: The theory of projection onto convex set (POCS) has been proposed [1], but it requires a large number of iterations for convergence. Methods using interleaved image blocks before the encoding were also suggested [2], but they are not in conformity with the coding standards. Lowpass filtering over the block-based coded images were also proposed [3], but it may cause serious distortions when the image contains high frequency components. Some adaptive filtering approaches have been proposed [4], but the cost is too high.

In this paper, we propose a bi-domain de-blocking technique, which samples the shifted image block at certain fixed locations and discards some high frequency components of the corresponding transformed block. By solving for the remaining unknown pixel values and the transformed coefficients, a less blocky image is obtained. This idea has been carried out for the Discrete Cosine Transform (DCT) and

the Slant Transform. It is found that the proposed bi-domain de-blocking technique reduces blocking artifacts effectively.

2. Vector Representation of an Image Transform

In the application of transform techniques to image processing, a linear separable orthonormal block transform with block size *8x8* can be expressed as $\mathbf{Y} = \mathbf{F} \cdot \mathbf{X} \cdot \mathbf{F}^{\mathbf{T}}$, where $\mathbf{X}$ is the *8x8* image block, $\mathbf{Y}$ is the *8x8* transformed block and $\mathbf{F}$ is the *8x8* transformed matrix. Every element in the matrix $\mathbf{Y}$ can be expressed as:

$$y_{pq} = \sum_{m=1}^{8} \sum_{n=1}^{8} f_{pk} \cdot x_{km} \cdot f_{qm} \,, \tag{1}$$

where x_{km} is at the kth row and m^{th} column of matrix $\mathbf{X}$, f_{ij} is at the ith row and j^{th} column of matrix $\mathbf{F}$ and y_{pq} is at the pth row and q^{th} column of matrix $\mathbf{Y}$.

Since y_{pq} is a linear combination of x_{km}, we can express it as follows:

$$\begin{bmatrix} y_{11} \\ \vdots \\ y_{pq} \\ \vdots \\ y_{88} \end{bmatrix} = \begin{bmatrix} f_{11} \cdot f_{11} & \cdots & f_{1m} \cdot f_{1n} & \cdots & f_{18} \cdot f_{18} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ f_{p1} \cdot f_{q1} & \cdots & f_{pm} \cdot f_{qn} & \cdots & f_{p8} \cdot f_{q8} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ f_{81} \cdot f_{81} & \cdots & f_{8m} \cdot f_{8n} & \cdots & f_{88} \cdot f_{88} \end{bmatrix} \cdot \begin{bmatrix} x_{11} \\ \vdots \\ x_{mn} \\ \vdots \\ x_{88} \end{bmatrix}. \tag{2}$$

The above equation is a vector representation of an image transform from an image vector $\mathbf{x}$ to a transformed vector $\mathbf{y}$ with $\mathbf{y} = \mathbf{C} \cdot \mathbf{x}$, where $\mathbf{C}$ is a *64x64* matrix and $\mathbf{x}$ is a *64x1* column vector. Similarly, the inverse transform can be represented as $\mathbf{x} = \mathbf{T} \cdot \mathbf{y}$ with $\mathbf{T} = \mathbf{C}^{-1}$, where $\mathbf{T}$ is a *64x64* matrix and $\mathbf{y}$ is a *64x1* column vector.

3. Blocking Effect Model

By shifting the block-based coded image four pixels both horizontally and vertically, the visible edge is at the middle of the shifted image block. This shifted image block can be modeled using four *4x4* matrices [5] as follows:

$$X = \begin{bmatrix} a_{4x4} & b_{4x4} \\ c_{4x4} & d_{4x4} \end{bmatrix}. \tag{3}$$

If the compression ratio of the block-based coder is too high that all the AC coefficients of the block-based coded image are quantized to zero, then the four matrices of the shifted image block become four constant matrices. Consequently, we only have four different pixel values (*a*, *b*, *c* and *d*) in the shifted coded image block.

4. Bi-domain De-blocking Algorithm

Let x_{ij}^{old} be the ith row and j^{th} column of the unprocessed shifted image block and y_{ij}^{old} be the ith row and j^{th} column of the corresponding transformed block. Similarly, let x_{ij}^{new} be the ith row and j^{th} column of the processed shifted image block and y_{ij}^{new} be the ith row and j^{th} column of the corresponding transformed block.

For the ideal terrace image block, that is, there are only four different pixel values in the shifted image block, the minimum number of the sampling points in the pixel domain is four. In order to reduce the blocking artifacts, those sampling points should be sampled as far to the block edge as possible. Hence, we sample at the corners of the shifted image block and we have $x_{11}^{old}=x_{11}^{new}$, $x_{18}^{old}=x_{18}^{new}$, $x_{81}^{old}=x_{81}^{new}$, $x_{88}^{old}=x_{88}^{new}$. For the other pixel values, we let them to be unknown at this stage and to be determined in the next stage.

In the transformed domain, some coefficients, especially the high frequency components, suffer from the blocking artifacts because the block edge always contains high frequency components. Hence, in order to reduce the blocking artifacts, we should discard the high frequency components, that is, setting $y_{ij}^{new}=0$ for some i, j. For the remaining transformed coefficients, we let them to be unknown at this stage.

According to the sampling scheme mentioned above, we can pick up the corresponding rows in equation (2) and break down the matrix multiplication into a sum of two matrix multiplications, as follows:

$$\begin{bmatrix} x_{11} \\ x_{18} \\ x_{81} \\ x_{88} \end{bmatrix} = \begin{bmatrix} \cdots & t_{1,8\cdot(p-1)+q} & \cdots \\ \cdots & t_{8,8\cdot(p-1)+q} & \cdots \\ \cdots & t_{57,8\cdot(p-1)+q} & \cdots \\ \cdots & t_{64,8\cdot(p-1)+q} & \cdots \end{bmatrix} \cdot \begin{bmatrix} \vdots \\ y_{pq} \\ \vdots \end{bmatrix} + \begin{bmatrix} \cdots & t_{1,8\cdot(m-1)+n} & \cdots \\ \cdots & t_{8,8\cdot(m-1)+n} & \cdots \\ \cdots & t_{57,8\cdot(m-1)+n} & \cdots \\ \cdots & t_{64,8\cdot(m-1)+n} & \cdots \end{bmatrix} \cdot \begin{bmatrix} \vdots \\ y_{mn} \\ \vdots \end{bmatrix}, \quad (4)$$

where $t_{i,j}$ is at the ith row and j^{th} column of the matrix $\mathbf{T}$. The above equation can be expressed in the form of $\mathbf{x_1}=\mathbf{S_1}\cdot\mathbf{y_1}+\mathbf{S_2}\cdot\mathbf{y_2}$, where $\mathbf{y_1}$ is a vector containing the low frequency components, $\mathbf{y_2}$ is a vector containing the high frequency components, and $\mathbf{x_1}$ is the vector containing the four corners of the shifted image block. $\mathbf{S_1}$ and $\mathbf{S_2}$ are the corresponding matrices.

Since we keep four pixel values unchanged after processing, we can set up four linear independent equations in the spatial domain. In order to find out the unknown pixel values, we need to set sixty transformed coefficients to zero ($\mathbf{y_2^{new}}=\mathbf{0}$) and find out the remaining four transformed coefficients ($\mathbf{y_1^{new}}$). The detail procedure is as follows:

Since $\mathbf{x_1}$ remains unchanged after processing, we have $\mathbf{x_1^{new}}=\mathbf{x_1^{old}}$. As we discard the high frequency components of the processed shifted image block, so we have $\mathbf{y_2^{new}}=\mathbf{0}$. This implies that $\mathbf{x_1^{new}}=\mathbf{x_1^{old}}=\mathbf{S_1}\cdot\mathbf{y_1^{new}}=\mathbf{S_2}\cdot\mathbf{y_1^{old}}+\mathbf{S_2}\cdot\mathbf{y_2^{old}} \Rightarrow \mathbf{y_1^{new}}=\mathbf{S_1^{-1}}\cdot\mathbf{x_1^{old}}$. Figure 1 shows the block diagram of the proposed algorithm.
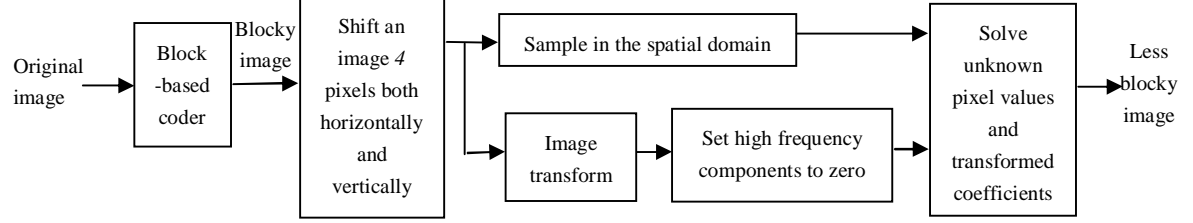
Fig. 1. Block diagram of the proposed de-blocking technique

The idea is applied to the Discrete Cosine Transform (DCT) and the Slant Transform (ST) as follows:

4.1 Discrete Cosine Transform (DCT)

It can be shown that the only non-zero DCT coefficients for the ideal terrace image block are located at the positions (p,q) for $p=1,2,4,6,8$ and $q=1,2,4,6,8$. The lowest four frequency components are at the positions $(1,1)$, $(1,2)$, $(2,1)$ and $(2,2)$. Hence, we set $\mathbf{y_1^{new}}=[y_{11}^{new} \ y_{12}^{new} \ y_{21}^{new} \ y_{22}^{new}]^T$. As $\mathbf{x_1^{new}}=\mathbf{x_1^{old}}=[a \ b \ c \ d]^T$ and $\mathbf{y_1^{new}}=\mathbf{S_1^{-1}} \cdot \mathbf{x_1^{old}}$. It can be shown that $y_{11}^{new}=2*(a+b+c+d)$, $y_{12}^{new}=1.4419*(a-b+c-d)$, $y_{21}^{new}=1.4419*(a+b-c-d)$ and $y_{22}^{new}=1.0396*(a-b-c+d)$. By doing the IDCT, that is, $\mathbf{X^{new}}=\mathbf{F^T} \cdot \mathbf{Y^{new}} \cdot \mathbf{F}$, where $\mathbf{F}$ is the DCT matrix, and expanding this IDCT equation, it can be shown that the pixel values in the reconstructed image block is $x_{km}^{new}=2*(a+b+c+d)*f_{1m}*f_{1k}+1.4419*(a-b+c-d)*f_{2m}*f_{1k}+1.4419*(a+b-c-d)*f_{1m}*f_{2k}+1.0396*(a-b-c+d)*f_{2m}*f_{2k}$, for $k=1,2,...,8$ and $m=1,2,...,8$. This equation can be expressed in the form of $\mathbf{X^{new}}=a*\mathbf{A}+b*\mathbf{B}+c*\mathbf{C}+d*\mathbf{D}$, where $\mathbf{A}$, $\mathbf{B}$, $\mathbf{C}$ and $\mathbf{D}$ are constant matrices and image independent and are shown in figure 2 diagrammatically. These four matrices can be viewed as the interpolation matrices. Since these interpolation matrices are smooth, so the reconstructed image block is also smooth and the blocking artifacts are reduced.
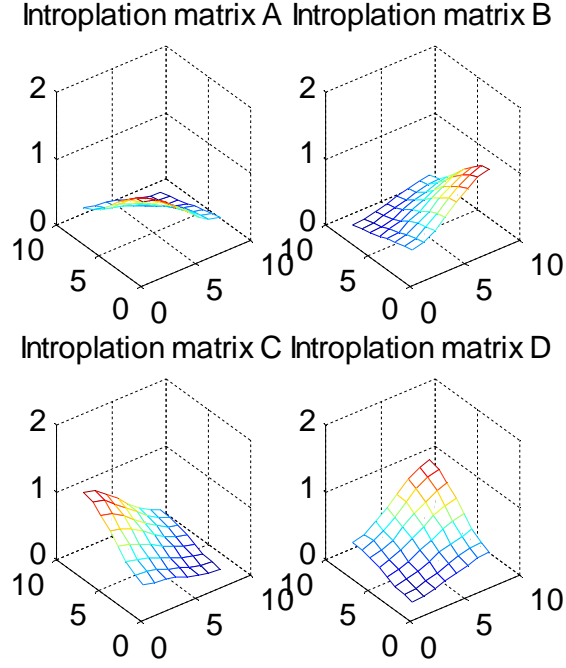
Introplation matrix A Introplation matrix B

Introplation matrix C Introplation matrix D

Fig. 2. Interpolation matrices for DCT de-blocking technique

4.2 Slant Transform (ST)

Similarly, it can be shown that the transformed coefficients for the ideal terrace image block are non-zero only at the positions (p,q) for $p=1,2,6$ and $q=1,2,6$. Hence, we can set $\mathbf{y_1^{new}}=[y_{11}^{new}\ y_{12}^{new}\ y_{21}^{new}\ y_{22}^{new}]^T$ and set the remaining sixty coefficients to zero ($\mathbf{y_2^{new}=0}$), and use the same method as before to find $\mathbf{X^{new}}$. It can be shown that $y_{11}^{new}=2*(a+b+c+d)$, $y_{12}^{new}=1.3093*(a-b+c-d)$, $y_{21}^{new}=1.3093*(a+b-c-d)$ and $y_{22}^{new}=6/7*(a-b-c+d)$. The reconstructed image block ($\mathbf{X^{new}}$) is now interpolated by four new constant matrices $\mathbf{A'}$, $\mathbf{B'}$, $\mathbf{C'}$ and $\mathbf{D'}$ as shown in figure 3.

Introplation matrix A   Introplation matrix B

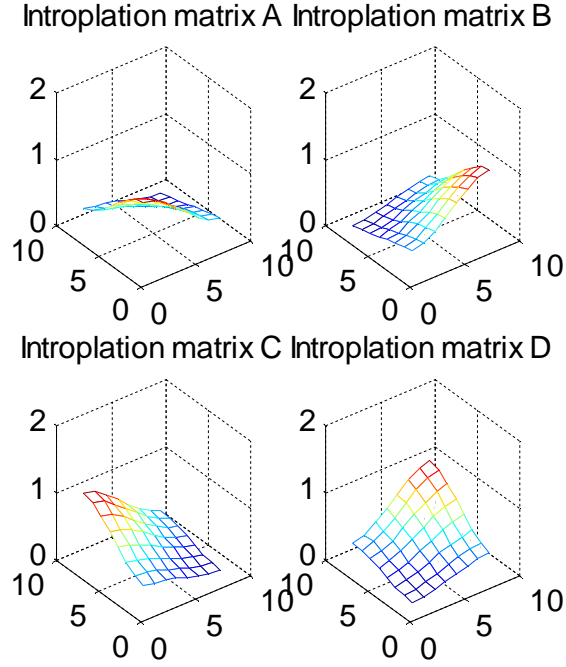Introplation matrix C   Introplation matrix D

Fig. 3. Interpolation matrices for Slant de-blocking technique

5   Simulation Results

The DCT de-blocking technique and the Slant de-blocking technique are applied to the JPEG-coded images "Tiffany", "Cancer" and "Woman" of size *512x512* adaptively. The effectiveness of the proposed algorithm is estimated by both quantitative measurement and qualitative evaluation.

For the quantitative measurement, the blocking artifact is mainly due to the grid noise in the monotone areas. The intensity of the monotone areas of a natural image usually changes very slowly, but there is a tendency for the intensity in the block-based coded image to change abruptly from one block to another as modeled in the section 3. Therefore, we propose the following methodology to measure the quantitative result:

If the four neighbor *8x8* image blocks are all DC blocks, that is, all the pixel values in the individual block are constant, then we sum up the error square in these four blocks, and compute the mean square error (*MSE*) of all these blocks as follows:

$$MSE = \frac{1}{N} \cdot \sum_{(i,j) \in Q} \left[R(i,j) - O(i,j) \right]^2 \ , \tag{5}$$

where **O** is the original image, **R** is the reconstructed image, **Q** is the region where there are four neighbor *8x8* DC blocks and *N* is the total number of pixels in **Q**.

Table 1 shows the comparison of the results of applying some common existing methods and our proposed de-blocking techniques. It can be seen from table 1 that our proposed algorithm gives better quantitative results than that of the existing methods. The qualitative results shown in the figure 4 also show that our proposed algorithm gives a better image quality than that of the existing methods.
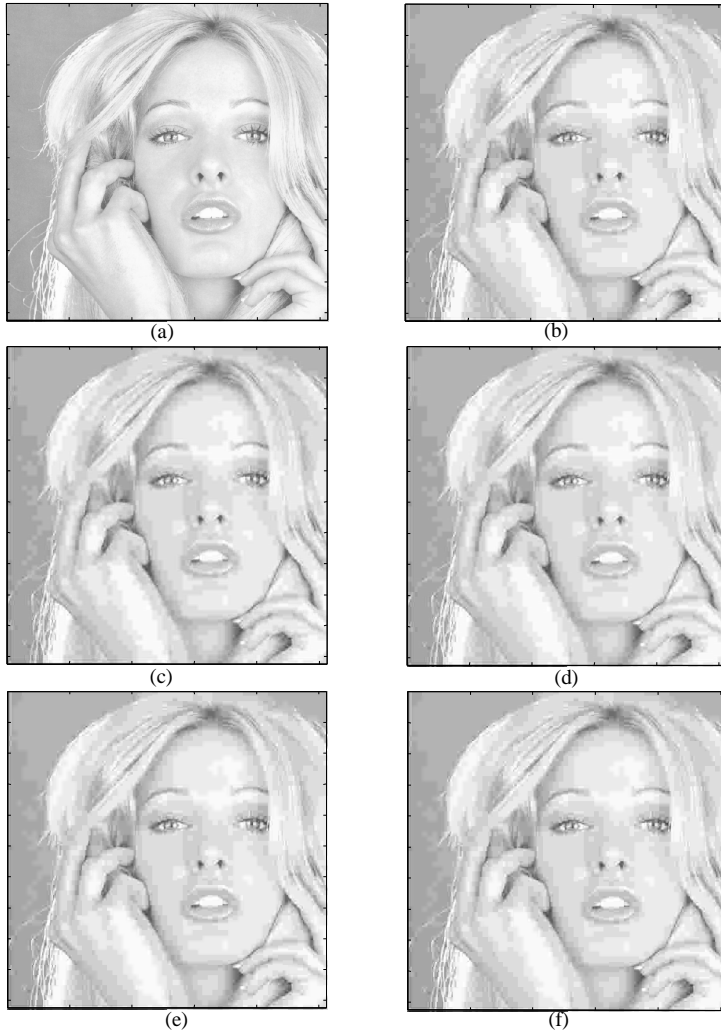
(a)

(b)

(c)

(d)

(e)

(f)

Fig. 4. (a) Original image (b) JPEG-coded image (c) Image processed by zero-masking technique [5] (d) Image processed by DCT coefficient weighting technique [5] (e) Image processed by Slant de-blocking (f) Image processed by DCT de-blocking technique

	Tiffany(0.238bpp)	Cancer(0.139bpp)	Woman(0.223bpp)
JPEG coded image	32.6421	22.6819	24.8619
DCT zero-masking technique [5]	30.4607	19.2036	21.6293
DCT coefficient weighting technique [5]	29.4858	19.0579	20.9516
Bi-domain DCT de-blocking technique	26.9824	16.7301	19.908
Bi-domain Slant de-blocking technique	27.0419	16.4105	20.5486

Table 1. Simulation results of calculated MSE by applying some common existing methods and our proposed algorithms

6   Concluding Remarks

In this paper, we propose a bi-domain de-blocking technique, which samples some pixel values in the shifted image block and discards some high frequency components in the corresponding transformed block. By solving for the remaining unknown pixel values and the transformed coefficients, we obtain a less blocky image.

The proposed algorithm can be applied to the enhancement of very high compression ratio block-based coded images. The given image can be first compressed to a very high compression ratio image through the block-based coder, and then the blocky image is enhanced by the proposed algorithm. The simulation results using the Discrete Cosine Transform and the Slant Transform show that the blocking artifacts are reduced significantly.

Further research work will study the effect on the image quality of the number of sampling points and the number of discarded transformed coefficients. The positions of the sampling points and the transformed coefficients will also be considered.

Acknowledgement

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