IMAGE DEBLOCKING USING DUAL ADAPTIVE FIR WIENER FILTER IN THE DCT TRANSFORM DOMAIN

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ABSTRACT

Blocking artifacts exist in images and video sequences compressed to low bit rates using block discrete cosine transform (DCT) compression standards. In order to reduce blocking artifacts, a novel DCT domain technique is presented in this paper. Firstly, a new FIR Wiener filter which exploits the dependence of neighboring DCT coefficients based on the linear minimum mean-square-error (LMMSE) criterion is proposed. Then we apply the new FIR Wiener filter twice in a dual adaptive Wiener filtering structure. In addition, an efficient parameter estimation method is proposed for the designed filter. Experimental results show that the performance of the proposed method is comparable to the state-of-the-art methods but has low computational complexity.

Index Terms—Blocking artifacts, FIR Wiener filter, DCT coefficient, dual adaptive filtering, parameter estimation

1. INTRODUCTION

Block based discrete cosine transform (BDCT) coding is adopted in several industry standards, such as JPEG, MPEG-4 and H.264/AVC, for image and video compression. In a BDCT based scheme, an image is firstly divided into non-overlapping blocks and pixels in each block are transformed into the DCT coefficients which are then quantized. At low bit rates, blocking artifacts will be visible because quantization is performed independently at each block.

The use of a post-processing technique on a decoded image is a common strategy to reduce blocking artifacts, as it does not require changing of existing standards. A number of post-processing techniques were proposed in recent years [1]-[10]. Therein, post-filtering in the DCT domain for the restoration of the DCT coefficients [9][10] has been shown to be a promising deblocking technique, since quantization of the DCT coefficients is the sole error source.

Our proposed method aims to reduce blocking artifacts based on the restoration of quantized DCT coefficients in the DCT domain. We designed a new FIR Wiener filter which exploits the correlation between neighboring DCT coefficients based on the linear minimum mean-square-error (LMMSE) criterion. Then we apply the proposed filter twice in a dual adaptive Wiener filtering structure. Experimental results show that the proposed method offers excellent deblocking performance, not only on objective measure, but also on subjective visual quality. Another advantage of the proposed method is its low computational complexity, making it suitable for real-time applications.

2. THE PROPOSED FIR WIENER FILTER

2.1. Quantization Model

Suppose $X$ represent the DCT coefficients of the original image and $Y$ represent the quantized DCT coefficients, so we have $Y = X + N$, where $N$ is the additive zero-mean noise introduced by the quantizers and contributes to the blocking artifacts in the coded image. The additive noise model is frequently used before and proves to be reasonable for quantization noise. The problem here is to estimate $X$ from $Y$ and the quantizer information.

2.2. The Context Window

Let $B_{m,n}$ be an 8×8 block at the $m$th block row and $n$th block column in an image, and $B_{m,n}^{k,l}$ be the block with $k$ shifts in the horizontal direction and $l$ shifts in the vertical direction, relative to the block $B_{m,n}$. Fig.1(a) gives two examples with $k=-1,l=-1$ and $k=1,l=0$ respectively.

When $|k| \leq 1$ and $|l| \leq 1$, there will be 8 shifted blocks $B_{m,n}^{k,l}$ neighboring to the block $B_{m,n}$. We apply the DCT on each of the shifted blocks. Hence, for each coefficient in $B_{m,n}$, there will be 8 neighboring coefficients from the 8 shifted blocks $B_{m,n}^{k,l}$ as shown in Fig. 1(b). We call this 3×3 context window. While $B_{m,n}^{k,l}$ represents $B_{m,n}$ shifted in the spatial domain, the DCT coefficients of $B_{m,n}^{k,l}$ can be computed using a fast algorithm [11] directly from the DCT coefficients of $B_{m,n}$. In other words, the conversion processes back and forth between the DCT domain and the spatial domain can be eliminated.
2.3. The Designed FIR Wiener Filter Using LMMSE

For each coefficient in the 8×8 block B_{m,n}, we denote it as Y_0. Let its neighboring coefficients from shifted blocks B_{m,n},|k|≤1, |l|≤1 be Y_i, i=1,2,...,K. Let the FIR filter coefficients be H_i, i=0,1,...,K, then the estimated coefficient \( \hat{Y}_0 \) is given by \( \hat{Y}_0 = \sum_{i=0}^{K} H_i Y_i \).

According to the linear minimum mean-square-error (LMMSE) criterion, the filter coefficients are:

\[
H_i = \arg \min E[\{\hat{Y}_0 - X_i\}] = \arg \min E[\{\sum_{j=0}^{K} H_j Y_j - X_i\}],
\]

where \( X_i \) is the original DCT coefficient before quantized. Let \( R_s(i,j) = E[Y_i Y_j] \) be the autocorrelation of the quantized DCT coefficients and \( R_{XY}(i,j) = E[Y_i X_j] \) be the cross-correlation between the quantized DCT coefficients and the original DCT coefficients. After some derivation, we have:

\[
\sum_{j=0}^{K} H_j R_s(i,j) = R_{XY}(0,j), j = 0,1,...,K.
\]

Thus, the FIR filter coefficients \( H_i, i=0,1,...,K \) can be determined from (2).

If we build the FIR filter on basis of the 3×3 context window, then we have a 9th order Wiener filter, i.e. \( K=8 \). Because of symmetric property of the context window as shown in Fig. 2(a), the 9th order Wiener filter can be simplified and its output will be represented as the average output of four 4th order Wiener filters.

We assume that quantization noise \( N \) has a zero-mean uniform distribution which can be determined from the quantization table. We also assume the DCT coefficients and quantization noise are uncorrelated.

\[
R_s(i,j) = R_s(i,j), \quad R_{XY}(i,j) = R_{XY}(i,j).
\]

If the DCT coefficients also have zero mean, then (2) can be expressed as:

\[
\begin{bmatrix}
1 + \frac{\sigma_N^2}{\sigma_X^2} & \rho_{0,1} & \rho_{0,0} & \rho_{1,1} \\
\rho_{0,1} & 1 + \frac{\sigma_N^2}{\sigma_Y^2} & \rho_{0,3} & \rho_{0,0} \\
\rho_{0,0} & \rho_{1,3} & 1 + \frac{\sigma_N^2}{\sigma_Z^2} & \rho_{0,0} \\
\rho_{1,1} & \rho_{0,0} & \rho_{0,3} & 1 + \frac{\sigma_N^2}{\sigma_X^2}
\end{bmatrix}
\begin{bmatrix}
H_0 \\
H_1 \\
H_2 \\
H_3
\end{bmatrix} = \begin{bmatrix}
1 \\
\rho_{0,1} \\
\rho_{0,0} \\
\rho_{0,0}
\end{bmatrix},
\]

where \( \sigma_N^2 \) is the quantization noise variance. We use the uniform distribution variance model \( \sigma_N^2 = Q^2 / 12 \), where \( Q \) is the quantization step; \( \sigma_X^2 \) is the priori variance of the original DCT coefficients; \( \rho_{0,1,0,0,1,1} \) are the normalized correlation coefficients between \( Y_0, Y_1, Y_2, Y_3 \) separately as shown in Fig. 2(b).

With these statistical parameters, FIR Wiener filter coefficients \( H_0,H_1,H_2 \) and \( H_3 \) can be determined. Because of the symmetric property, parameters of the four 4th order Wiener filters are approximately the same, thus we only need to compute once to obtain these filter coefficients.

Thus, the estimated DCT coefficient \( \hat{Y}_0 \) is given below:

\[
\hat{Y}_0 = H_0 Y_0 + \frac{H_1}{2}(Y_1 + Y_2) + \frac{H_2}{4}(Y_3 + Y_4 + Y_5 + Y_6).
\]

The derivation above assumes that the DCT coefficients have zero mean. Suppose the priori mean of the original DCT coefficients \( X \) are \( \bar{X} \), then DCT coefficients will be zero-mean after subtracting the priori mean. Thus, with the estimated priori mean \( \bar{X} \), the restored DCT coefficients \( \hat{Y} \) can be obtained using

\[
\hat{Y} = X + H(Y - \bar{X}),
\]

where \( H \) is the proposed FIR Wiener filter applied on the 3×3 context window. We shall explain how to estimate the parameters of the proposed filter and the priori mean in section 3.

3. THE DUAL ADAPTIVE WIENER FILTERING STRUCTURE

3.1. The Proposed Structure Description

We apply the new FIR Wiener filter twice in a dual adaptive filtering structure as shown in Fig 3. The first filtered result is taken as the pilot information, from which parameters are estimated for the second FIR Wiener filter. It is our prior knowledge that the original DCT coefficients must lie within the quantization intervals determined by the quantization step. So in our proposed structure, “restriction”
should be imposed after each filtered DCT coefficient.

\[ \hat{Y} = \hat{X} + H(Y - \hat{X}) \]

which is the first Wiener filter procedure. After that, the priori mean and variance will be estimated more accurately from the updated DCT coefficients \( \hat{Y} \) as: \( \hat{X}, \sigma^2_{\hat{X}} = \sigma^2_Y \) for the second FIR Wiener filter.

\[ b. \text{Normalized correlation coefficients } \rho_{l,0}, \rho_{l,1}, \rho_{l,1} \]

The DCT coefficients at 64 different frequencies for each block have their specific autocorrelations. The autocorrelations can be estimated from the original DCT coefficients using the definition of normalized correlation coefficients between two random variables \( r \) and \( s \):

\[ \rho = \frac{E[(r - \bar{r})(s - \bar{s})]}{\sqrt{E[(r - \bar{r})^2]E[(s - \bar{s})^2]}} \tag{8} \]

The autocorrelations can be trained from sample images and then used as a table to look up.

5. EXPERIMENTAL RESULTS AND ANALYSIS

Three quantization tables Q1, Q2, and Q3 corresponding to 0.24, 0.189 and 0.15 bits per pixels (bpp) are used for the experiments. Table 1 summarizes the PSNR results of our method and other popular deblocking methods. In most cases, the proposed method has the highest PSNR gain except the image “Lena” using the quantization tables Q1 and Q2 for which Sun’s method [7] is slightly better. We have also provided the visual comparison of different deblocking methods through the image “Lena” shown in Fig. 4. We can find that the proposed method effectively removes most of annoying artifacts and preserves edges and texture well. The results of MPEG4-2, POCS Y, WT X, POCS R, and WT L leave some artifacts unprocessed, while the processed images of Sun’s method and our method give the best visual quality improvement.

In the proposed technique, the computational complexity is mainly introduced by the computation of the DCT coefficients from shifted blocks. The author in paper [11] proposed a fast algorithm to obtain the DCT coefficients of new shifted blocks directly from the DCT coefficients of original blocks. The complexity depends on the number of zero DCT coefficients in each block, which is related to the compression ratios of the input images.

Since we process low-bit-rate coded images with very high compression ratios, the fast algorithm is supposed to save much computational cost. It should be noted that the performance of our method is comparable to Sun’s method, but as to the latter one, MAP criterion is adopted to minimize the energy function which requires iterations to obtain the optimal results, therefore, our method has a much lower computational complexity than Sun’s.

6. CONCLUSIONS
In this paper, a DCT domain algorithm is proposed to reduce blocking artifacts for low bit rate coded images. We propose to design a new FIR Wiener filter with an effective parameter estimation strategy and apply a dual adaptive Wiener filtering structure to restore each DCT coefficient. Experimental results on some images have demonstrated the effectiveness of the proposed DCT domain method. From the comparison with the other deblocking methods, we can say that the performance of our method is comparable to the state-of-the-art methods but has low computational complexity.

7. REFERENCES


Table 1. PSNR results (db) processed by different methods using Q1, Q2, Q3.

<table>
<thead>
<tr>
<th>Lena</th>
<th>Barbara</th>
<th>Baboon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantization Table</strong></td>
<td><strong>Q1</strong></td>
<td><strong>Q2</strong></td>
</tr>
<tr>
<td><strong>Coded Image</strong></td>
<td>30.702</td>
<td>30.091</td>
</tr>
</tbody>
</table>

Fig. 4. The processed result using different methods for “Lena”