LOCALIZED FILTERING FOR ARTIFACT REMOVAL IN COMPRESSED IMAGES

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ABSTRACT
The paper proposes a novel method for coding artifact reduction in compressed images. For removing blocking artifacts, a localized DCT-based filter with condition on the similarity between surrounding blocks is considered. To reduce ringing, a localized fuzzy filter is utilized to avoid the blurry effect of linear filter and painting-like effect of conventional fuzzy filter. To enhance chroma components and reduce the color bleeding, the localized filter for luma component are implemented for the chroma components. Simulations on a wide range of compressed images are performed to verify the effectiveness of the algorithm.

Index Terms— coding artifact reduction, fuzzy filter, localized filtering.

1. INTRODUCTION
Visual quality of block-based compressed images is degraded by blocking artifacts, ringing artifacts and color bleeding, especially at low-bit-rate coding. Blocking artifacts occur at the border of neighboring blocks when each block is processed independently with coarse quantization of discrete cosine transform (DCT) coefficients. In natural images, high frequency components tend to have smaller values than the low frequency components. But they are quantized with higher quantization step size than the low frequency components. This makes the high frequency components more distorted or even rounded to zero value. Loss in high frequencies will cause ringing artifacts, which affect the visual quality seriously in detail areas. For chroma components, they are downsampled and then compressed with even higher quantization matrix than the luma components. Color becomes blocky and mismatches to its luma information. These lead to color bleeding.

Visual effects of coding artifacts vary from one codec to another but these artifacts always have directional and data-dependent properties. Because of the block-based compression, blocking artifacts in luma and chroma components occur at the horizontal and vertical directions at pixels between 2 blocks. Furthermore, due to the loss of high frequency components during the coarse quantization, the ringing artifacts appear along the strong edges. The data dependent property is from the usage of the same quantization step size matrix for every blocks. Coding artifacts degrade the visual quality more in detail areas than in flat areas. These characteristics make the coding artifacts different than the recording noise, where it is usually assumed as additive zero-mean white Gaussian noise [1]. Fig. 1 shows the differences between additive Gaussian noise and coding artifacts in MJPEG compression. The noisy image in Fig. 1.(a) is degraded by additive Gaussian noise with variance of 0.01 while the compressed image in Fig. 1.(b) is encoded with scaling factor of 4

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Fig. 1. Comparison on visual effect between coding artifacts and Gaussian noise.

for the quantization step size matrix. As shown in this example, Gaussian noise is uniformly distributed over pixels while the coding artifacts is non-uniformly distributed due to their special characteristics. This implies that these coding artifacts should be treated in a different way than methods for denoising in pre-processing.

Many pixel-domain and DCT-domain post-processing approaches have been considered for blocking artifact reduction. These include low-pass filtering [2] and adaptive median filtering [3] which were applied to remove the high frequencies caused by sharp edges between adjacent blocks. In H.264/AVC, an adaptive deblocking filter [4] was proposed to selectively filter the artifacts in the coded block boundaries. With assumption on the small changes of neighboring DCT coefficients at the same frequency in a small region, a fixed low pass filter in [5] or adaptively weighted low pass filters in [6] and [7] are applied to transform coefficients of the shifted blocks. Although effectively reducing the blocking artifacts, these mentioned methods also blur the output images.

To reduce ringing artifacts, edges or edgy areas which contain ringing are detected and then are processed with an adaptive filter as in [8] or a gray-level morphological nonlinear smoothing filter as in [9]. These filters remove the ringing artifacts, but at the same time also reduce the details of the images. To avoid the blurry effect, isotropic fuzzy filters [10] filters are used, but their output sometime have painting-like effects with very strong edges above smooth areas.

This paper proposes a novel method to reduce the blocking, ringing and color bleeding artifacts using localized filtering. For de-blocking, a conditionally lowpass filter is applied for local shifted blocks around the block of interest. To avoid blurry effect, a novel fuzzy filter is proposed for deringing. Filter coefficients of this filter are weightedly locally to reduce the painting-like effect of fuzzy filters. The paper is organized as follows. Section 2 introduces the conditionally localized DCT-based filters for deblocking. Section 3 describes the localized fuzzy filter for deringing. Simulations and
Fig. 2. Translation between blocks of image $x_s$ and $x$.

correlation between the scaled and quantized values. Because of the block-size processing, the correlation between the $N \times N$ block of pixels is destroyed. To increase this cross-block correlation, a DCT-based domain low pass filter [6] is applied through the surrounding $N \times N$ blocks $Y_q(m + m_i, n + n_i)$ together with the block of interest $Y_q(m, n)$, as shown in Fig.2. Assume that the DCT transform (type II) of block $Y_q(m + m_i, n + n_i)$ is $\tilde{Y}_{q,m_i,n_i}$, 

\[
\tilde{Y}_{q,m_i,n_i}(u, v) = \frac{2}{N} k_u k_v \sum_{m=0}^{N-1} \sum_{n=0}^{N-1} Y_q(m + m_i, n + n_i) C_u^m C_v^n
\]

for $m, n = 0, \ldots, N - 1$ (1)

and $\tilde{Y}_{q,0,0} = X_q$ where the shifted motion vector is considered equal to 0. The localized DCT-based deblocking filter is applied to the DCT coefficients at the same coefficient of these local DCT coefficients to form the enhanced DCT coefficients $\tilde{Y}_q(u, v)$, 

\[
\tilde{Y}_q(u, v) = \sum_{(m_i, n_i) \in \Omega_{DB}} W_{DB}(m_i, n_i) \tilde{Y}_{q,m_i,n_i}(u, v)
\]

for $u, v = 0, \ldots, N - 1$. (2)

where $W_{DB}$ is the lowpass filter coefficients for deblocking and $\Omega_{DB}$ is the local window centered at location $(m, n)$ which consists all $(m_i, n_i)$. To avoid the reconstructed output $\tilde{Y}_q$ biasing from $\tilde{Y}_q$, the filter coefficient must satisfy

\[
\sum_{(m_i, n_i) \in \Omega_{DB}} W_{DB}(m_i, n_i) = 1 \quad \forall(m_i, n_i) \in \Omega_{DB}
\]

Normally

\[
W_{DB}(0, 0) \geq W_{DB}(m_i, n_i). \quad (4)
\]

so that the DCT coefficients of the center blocks have highest contribution to the output. The enhanced $N \times N$ block $\tilde{Y}_q$ is reconstructed by inverse DCT transform. For highly compressed images, the high DCT frequencies tend to have zero value. As can be seen in (2), these coefficients are recreated because of the non-zero values of $\tilde{Y}_{q,m_i,n_i}(u, v)$. In [11], a condition of quality enhancement was considered for the linear temporal filter over many frames. It is shown that the difference between the block of interest and the temporally surrounding blocks must be small enough so that these blocks are rather related to each other to achieve the quality improvement. Similarly in this paper for image enhancement, a condition of the small difference between the block of interest and the spatially surrounding blocks is implemented as follows

\[
\sum_{m=0}^{N-1} \sum_{n=0}^{N-1} |Y_q(m + m_i, n + n_i) - Y_q(m, n)| \leq Th
\]

where $Th$ is a threshold. Only surrounding blocks which satisfy this condition will be locally filtered using coefficients $W_{DB}(m_i, n_i)$.

3. LOCALIZED FUZZY DERINGING FILTERS

Although the localized deblocking filters as described in Section 2 can reduce the blocking artifacts and ringing artifacts, it will blur the images due to its lowpass filtering. The deblocking filter should be only applied to pixels near to block borders, not all pixels in the blocks

\[
Y_{DB}(m, n) = \begin{cases} 
Y_q'(m, n) & \text{if } (m, n) \text{ near to block borders} \\
Y_q(m, n) & \text{otherwise} 
\end{cases} \quad (6)
\]

To reduce the ringing artifact, this section will discuss a novel localized fuzzy filters. Fuzzy filters are non-linear filters which are based on the real-valued spatial-rank relation, as described in [10][12]. Assume that a normalized fuzzy filter $h_{DR,n}$ is applied to a set $\Omega_{DR}$ of neighboring samples $Y_{DB}(m + m_i, n + n_i)$ around the input $Y_{DB}(m, n)$ to form the output

\[
Y_{DR}(m, n) = \sum_{(m_i, n_i) \in \Omega_{DR}} h_{DR,n}(m_i, n_i) Y_{DB}(m + m_i, n + n_i) \quad (7)
\]

where $h_{DR,n}(m_i, n_i)$ is calculated by

\[
h_{DR,n}(m_i, n_i) = \frac{h_{DR}(Y_{DB}(m + m_i, n + n_i), Y_{DB}(m, n))}{\sum_{(m_i, n_i) \in \Omega_{DR}} h_{DR}(Y_{DB}(m + m_i, n + n_i), Y_{DB}(m, n))}
\]

where $h_{DR}$ is the filter coefficient which controls the contribution of the input $Y_{DB}(m + m_i, n + n_i)$ to the output. Fuzzy filters are signal dependent and help removing the ringing artifact while preserving the details. They depend on the distance between the surrounding pixel $Y_{DB}(m + m_i, n + n_i)$ and the pixel of interest $Y_{DB}(m, n)$. Follow the spatial-rank relation, the filter coefficients $h_{DR}$ must fulfill the constraints

\[
\lim_{Y_{DB}(m + m_i, n + n_i) \to Y_{DB}(m, n)} h_{DR}(Y_{DB}(m + m_i, n + n_i), Y_{DB}(m, n)) = 1
\]

\[
\lim_{Y_{DB}(m + m_i, n + n_i) \to Y_{DB}(m, n)} h_{DR}(Y_{DB}(m + m_i, n + n_i), Y_{DB}(m, n)) = 0
\]

and

\[
h(Y_{DB}(m + m_i, n + n_i), Y_{DB}(m, n)) \geq h(Y_{DB}(m + m_i, n + n_i), Y_{DB}(m, n))
\]

\[
\text{if } |Y_{DB}(m + m_i, n + n_i) - Y_{DB}(m, n)| \leq |Y_{DB}(m + m_i, n + n_i) - Y_{DB}(m, n)|. \quad (11)
\]
Fig. 3. Localized coefficients of fuzzy filters.

\[ h_{DR}(Y_{DB}(m+n+m+n_i), Y_{DB}(m, n)) \]

\[ \geq h(Y_{DB}[m+m', n+n'], Y_{DB}[m, n]) \quad \forall (m', n'). \]  

(13)

For the same \( Y_{DB}[m+m', n+n'] - Y_{DB}[m, n] \), the higher the \( \sigma \) value, the higher the contribution of \( Y_{DB}[m+m', n+n'] \) relatively compared to the contribution of \( Y_{DB}[m, n] \) to the output. This implies that \( Y_{DB}[m, n] \) will be more averaged to \( Y_{DB}[m+m', n+n'] \). Smaller \( \sigma \) values will keep the signal \( Y_{DB}[m, n] \) more isolated from its neighboring samples.

An example of calculating the coefficients of the localized fuzzy filters is shown in Fig.3. The top right area visualizes the way calculating fuzzy coefficient at pixel \((m, n) = (1, -1)\). To estimate the spatial-rank relation between pixel of interest \((m, n) = (1, -1)\) and its surrounding pixel at \((2, -2)\), the conventional fuzzy filter is based only on the value of these two pixels using (12). If these two pixels represent an edge with similar values, its small difference leads to coefficients having values closed to unity (as observed from (9)). They would dominate the coefficients in other directions which are different than the edge direction. This will cause the painting-like effect. To reduce this effect, the spatial-rank relation is proposed to be a weighted combination of the spatial-rank relation of surrounding pairs of pixels where their position difference are \((m_i, n_i) = (1, -1)\). These relations are shown as the 45° arrows in the top right of Fig.3. The pairs of pixels are determined by the shift positions \((m_i, n_i) \in V\), where \(V\) is the \(3 \times 3\) local window centered by pixel at \((m, n) = (1, -1)\) in this example. Another example with \((m, n) = (-1, 2)\) and direction with \((m_i, n_i) = (-1, 0)\) is shown in the bottom left area of Fig.3.

\[ h_{DR}(Y_{DB}(m+n+m+n_i), Y_{DB}(m, n)) \]

\[ = \sum_{(m_i, n_i) \in V} \left( W_{DB}(m_i, n_i) \right) \times h_{DR,m_i,n_i}(Y_{DB}(m+m_i+m+n_i+n_i), Y_{DB}(m+m_i+n+n_i)) \]

(14)

\[ h_{DR,m_i,n_i}(Y_{DB}(m+m_i+m+n_i+n_i), Y_{DB}(m+m_i+n+n_i)) \]

For chroma components, the localized algorithm cannot base on \(U\) and \(V\) because they don’t have enough information. In this case, the algorithm is extended for chroma components by using the same localized fuzzy filter of luma component. This helps match the color to the structure in the luma component and reduce the color bleeding. The whole algorithm is shown in Fig.4. At first, all components are transformed to DCT domain and are deblocked using the localized linear filter. They are then converted back the pixel domain by IDCT transform. Next, the deblocked Y component is implemented to form the coefficients at the localized fuzzy filter, which is later used for deringing. For \(U\) and \(V\) components, they are upsampled to the same size of \(Y\) component, then are deringed by the localized fuzzy filter from luma.

4. SIMULATION RESULTS

Simulations are performed to verify the effectiveness of the localized filters in artifact reduction. The simulated database includes different types of images from video sequences: Foreman, News, Mother, Silent, Soccer, Bus. They are compressed using JPEG compression with different scaling factors \(k\) of the quantization matrix. For both deblocking and deringing localized filters, the weighting matrices \(W_{DB}\) and \(W_{DR}\) are \([1, 1, 1; 1, 1, 1; 1, 1, 1]/11\). The local windows \(\Omega_{DB}, \Omega_{DR}\) and \(V\) are all set as \(3 \times 3\) pixels. The threshold \(T_h\) in the deblocking part is set to \(250k^2\). Only \(2 \times 2\) pixels at each side of the block borders are replaced by the deblocked pixels to avoid the blurry effect which is mentioned in Section 3. The spread parameter of the fuzzy filter \(\sigma\) is also proportional to the scaling factor as \(5k\). For comparison, other methods of artifact reduction such as Chen’s method [6], Liu’s method [7] and Kong’s method [10] are also simulated. Fig.5 shows the zoomed-in result for the \(6^{th}\) frame of News sequence which is compressed with scaling factor of 3. Comparing to the compressed image in Fig.4(b), the enhanced images using Chen’s method (Fig.4(c)), Liu’s method (Fig.4(d)) and Kong’s method (Fig.4(e)) can reduce most of blocking artifact and ringing artifact. However they also introduce other artifacts such as blurriness (Chen’s and Liu’s methods) or painting-like effect with dominant edges and very few details (Kong’s method). The enhanced images using Chen’s method and Liu’s method are rather blurry and still have some ringing artifacts at strong edge areas. The enhanced image using Kong’s method is sharper with less ringing artifacts than the enhanced image using Chen’s method or Liu’s method. But it has the painting-like effect with cleared out details, as can be seen at the face of the spokeswoman. The enhanced image using the proposed localized filter in Fig.4(f) achieves the best visual quality comparing
The paper proposes a novel method for coding artifact reduction using a conditionally localized DCT-based filter for deblocking and a localized fuzzy filter for deringing. These filters effectively remove the coding artifacts while avoiding the blurry effect from linear filtering and painting-like effect from non-linear fuzzy filters. Future works will focus on adaptive localized filters and advanced methods for color bleeding reduction.

6. REFERENCES


