Tiling Artifact Reduction for JPEG2000 Image at Low Bit-Rate

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Abstract
JPEG2000 is a very promising still image standard because of its excellent performances. However, it also causes higher complexity to implement. In practice, in JPEG2000 coding systems, an image is segmented into serial tiles and each tile is compressed or transformed independently, thus creating tiling artifacts in the tile boundary. At low bit, tiling artifacts in JPEG2000 images are annoying. This paper introduced a new post-processing method to reduce this artifact, where max-lift wavelet subband decomposition was used and then subband coefficients were adaptively filtered and soft-thresholded. The post-processing is done out of JPEG2000 image coding systems, so it has no compatible problem with the JPEG2000 standard. Experiments showed that the post-processing was effective to obviously enhance the visual quality of the JPEG2000 image at low bit.

1. Introduction

From a functionality point of view, JPEG 2000 is a true improvement, providing lossy and lossless compression, progressive and multi-resolution bitstreams, error resilience, region of interest, random access and other features in one integrated algorithm [1]. However, it also causes higher complexity to implement. So, it is quite common to divide a picture into one or more pieces, which are called tiles, and then be compressed and decompressed independently, similar to JPEG coding systems. Although the tile size in JPEG2000 is much larger than the block size in JPEG (128×128 in JPEG2000 profile0 ), blocking artifacts named as tiling artifacts at tile boundaries are still noticeable at low bit rates. Those artifacts might not be acceptable. The artifacts at the tile borders are due to the fact that the wavelet transform is done using the symmetrical extension instead of the nearby tile coefficients, and embedded quantization errors caused by post-compression rate-distortion optimization worsen the tiling artifacts.

A few works about how to reduce this kind of artifacts have been done. In [2], a method of projection onto convex set was used in the encoder. But it is very difficult for pre-processing in encoder to reduce the artifacts. A point-symmetric extension method was proposed to replace the symmetric extension in JPEG2000 standard [3] to improve image quality, but it cannot significantly reduce tiling artifacts at low bit. In [4], the tile size was chosen to be odd to remove the tiling artifact. In [5], the paper depicted over-lapped wavelet transform. In [6], a pre-/post-filtering approach was presented for JPEG2000 tiling artifact removal, in which a pre-filter is applied at tile boundaries before wavelet compression, and a post-filter is invoked at the same locations after wavelet reconstruction. In a word, those approaches [4]-[6] are effective to reduce tiling artifacts. However, they need to read more than two tiles coefficients or be incompatible with JPEG2000 standard.

To reduce block artifacts in JPEG, various post-processing schemes have been proposed. One of them is to use wavelet-based subband decomposition [7]. In this paper, we apply similar philosophy to remove tiling artifact in JPEG2000 image. Our wavelet is a nonlinear wavelet: morphological max-lift wavelet. Because only tile boundary area of an image needs to be processed and this wavelet transform is based on lifting scheme, the computation complexity is significantly reduced. Experiments showed that at low bit rates, image quality, especially visual quality, is enhanced after post-processing.

2. Proposed Solutions

Accordingly to the characteristics of the tiling artifact, we put forward the following processes to reduce it.

At first, we have to determine the area that may appear the artifact. Figure1 illustrates that tiling artifact occurs around the tile boundaries and is extended to both sides along with decomposition levels. From observation, we can determine the width of the area...
is more than $2N_i + 1$ (for $(5, 3)$ filter) or $4N_i + 1$ (for $(9, 7)$ filter), where $N_i$ is the number of the decomposition levels. The area that needs to be processed is obtained like Figure 2.

After the area is determined, we consider reduction of tiling artifact in the wavelet domain. Wavelet filter is chosen to be morphological max-lift wavelet. The Figure 3 shows the overall block diagram of the proposed system. We named the tiling artifact area as the sub-image of the tiling image, namely I. At the horizontal orientation, I is down-sampled and decomposed into low pass subband L and high pass subband H. In the wavelet domain, low pass coefficients can preserve quite well local maxima and don’t create new maxima. The fact is helpful for the post filtering. Therefore, the low pass coefficients can be adaptively filtered accordingly to high pass coefficients, while high pass coefficients can be filtered by soft-threshold in order that the curve in the tile boundary is suppressed. After up-sampling, the filtered coefficients are synthesized into $I'$. Because an image is two-dimensional space, $I'$ should be again processed vertically the same as above procedure.

### 3. Max-Lift Morphological Wavelet

The lifting scheme is a method accomplishing multiresolution analysis similar to the wavelet transform, but it allows mixing nonlinear operator into the multiresolution transform and construct second-generation wavelet [8]. The lifting scheme includes three steps. It begins with a “Lazy wavelet transform”, namely to split the data into two smaller subsets, even and odd. Then, even samples are processed to predict the odd samples. The difference between the odd sample and the prediction value is the detail coefficient. In the third step, even samples are updated with detail to get scaled coefficients. Heijmans and Goutsias [9] used morphological operators—supremum (least upper bound) $\vee$ in the prediction step and the update step of lifting scheme and proposed a morphology-based multiresolution analysis called max-lifting scheme which maps the signal into nonlinear morphological spaces. The built second generation wavelet is called max-lift Morphological Wavelet.

The max-lifting scheme is as follows:

**Split step:**

$$x(n) = x(2n) \quad (1) \quad y(n) = y(2n + 1) \quad (2)$$

**Predict step:**

$$y'_1(n) = y_1(n) - (x_1(n) \vee x_1(n + 1)) \quad (3)$$

**Update step:**

$$x_1(n) = x_1(n) + (0 \vee y'_1(n - 1) \vee y_1(n)) \quad (4)$$

The above scheme is reversible so that the max-lift wavelet can have perfect reconstruction property. From figure 4, we can see that the high pass coefficients coarsely indicate the slope of the original signals; while low pass coefficients preserve quite well local maxima and don’t create new maxima. The fact is helpful for the post filtering.
4. Adaptive Filtering and Soft-threshold

Among many practical applications of image restoration, the constrained least squares restoration filter is widely used, because it can incorporate an optimal constraint into the restoration process without significantly computational overhead. The 1-D 5 tap lowpass filtering function is modeled by an approximated linear space-invariant filter whose point spread function is given as:

\[ h(n) = \frac{1}{20} \begin{bmatrix} 1 & 3 & 12 & 3 & 1 \end{bmatrix} \]  

(5)

According to the different magnitude of high pass coefficients, the function (5) is modified to implement adaptive filtering of low pass coefficients.

More specially, if the magnitude of high pass coefficient is much more than its two adjacent ones, the function \( h(n) \) (5) is modified as:

\[ h_1(n) = \frac{1}{10} \begin{bmatrix} 1 & 2 & 14 & 2 & 1 \end{bmatrix} \]  

(6);

If the magnitude of high pass coefficient is almost near to its two adjacent ones, the function \( h_2(n) \) (5) is modified as:

\[ h_2(n) = \frac{1}{10} \begin{bmatrix} 10 & 1 & 8 & 1 & 0 \end{bmatrix} \]  

(7);

When in other cases, the function \( h_3(n) \) is modified as:

\[ h_3(n) = \frac{1}{20} \begin{bmatrix} 1 & 5 & 8 & 5 & 1 \end{bmatrix} \]  

(8).

Donoho proposed a powerful noise reduction technique that attempts to suppress noise by threshold in the discrete wavelet transform (DWT) domain [10]. Thus we can further reduce artifact by soft-thresholding in high pass coefficients. Those high pass coefficients \( H(y)(n) \) are filtered by means of the soft-thresholding[10] according to equation (9)

\[ H(y)(n) = \begin{cases} \text{sign}(H(n))(|H(n)|-\delta) & |H(n)| > \delta \\ 0 & H(n) \leq \delta \end{cases} \quad t = \gamma \sqrt{2\ln N} \]  

(9)

where \( \gamma \) is noise level. The performance of thresholding depends on the threshold in (9). Therefore, the value of the noise level, which is an unknown priori, must be estimated from the wavelet coefficients of the observed image.

5. Experiments and Comparisons

In Figure 5, a piece of pixel values come from the tile boundary of the “Lenna” image with tiling artifacts. They were first transformed by wavelet subband decomposition. And then they were recovered through wavelet synthesizing after their subband coefficients were adaptively filtered and soft-thresholded. The Figure 5 shows that the true edge information was almost preserved and the curve due to the disconnection between neighborhood tiles is fitted.

![Figure 5. Comparison between a piece of original pixel values and recovered ones in the tile boundary.](image)

Images performance was objectively evaluated by calculating the peak signal-to-noise-ratio (PSNR) of them. PSNR is obtained by the following equation:

\[ PSNR = 10 \log \frac{D^2}{MSE} \]  

(10)

where \( D \) is the dynamic range of the pixel value and in this case, \( D = 255 \). Here, MSE is the mean-squared error between the original image and the one exiting tiling artifacts or between the original image and the post-processed one, calculated by

\[ MSE = \frac{1}{N} \sum \sum |I(x, y) - \hat{I}(x, y)|^2 \]  

(11)

where \( N \) is the number of pixels in the original image. \( I(x, y) \) and \( \hat{I}(x, y) \) denote the (x, y) pixel value of the original image and the processed one respectively.

We chose “cat”, “lenna”, “barbra” as test images and used the Kakadu version 3.4 JPEG 2000 software to code these images with low bit and 128×128 tile size. And then, these images, which had obvious tiling artifact, were post-processed by above method.

<table>
<thead>
<tr>
<th>Bit rates (bit/pixel)</th>
<th>0.12</th>
<th>0.14</th>
<th>0.18</th>
<th>0.20</th>
<th>0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No processed</td>
<td>20.40</td>
<td>22.91</td>
<td>25.68</td>
<td>26.88</td>
<td>28.24</td>
</tr>
<tr>
<td>Post-processed</td>
<td>20.44</td>
<td>22.94</td>
<td>25.72</td>
<td>26.95</td>
<td>28.30</td>
</tr>
<tr>
<td>Gain</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.07</td>
<td>0.06</td>
</tr>
</tbody>
</table>

According to PSNR values of Table 1, we can see that this post-processing method improved a little image quality. From Figure 6, we can see that the image with tiling artifact is enhanced through this post-processing, while its PSNR gain is smaller than results in [6]. It was proved that our post-processing algorithm is effective to improve the visual quality of the image with tiling artifact.
6. Conclusions

This paper proposes a post-processing method that can significantly reduce the tiling artifacts in low bit JPEG2000 images. We focus in this paper on the fact that tiling artifacts can be well separated in the subband domain, and that processing in the subband domain does not add new tiling artifacts. With these insights, the proposed methods used a nonlinear morphological wavelet, which can keep the edge information, and applied adaptive least minimum mean square error filtering on low pass subband and soft-thresholding of high pass subband. The proposed method is an effective way to improve the visual quality of JPEG2000 image at low bit.

Reference


Figure 6. A part of decoded image Barbara(0.2 bits/pixel, 5-level 9/7 wavelet, 128×128 tiles).(a) No processed , (b)Gain of PSNR of the image post-processed by our method is 0.10 db (c)Gain of PSNR of the image processed by pre-processing and post-processing method in [6] is 0.90 db, (d)Gain of PSNR of the image processed only by post-processing method in [6] is 0.41 db.