Ringing Artifacts Reduction using Adaptive Morphological filter for JPEG2000

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Abstract. The JPEG2000 is the latest presently image compression standard presented by International Standards Organization which enables compressed image at very low bit rates. At a very low bit rate, the reconstructed image contains visible ringing artifacts at the image edge. In order to reduce the ringing artifacts, we propose a new filter for filtering the ringing artifacts and enhance the processed image quality. The proposed algorithm is performed on the encoder and the decoder of JPEG2000. In the encoder, the compressed image is partitioned using the DFQP (DWT Feature Quad-tree Partition) and morphological operations are conducted to select the optimal structure element in order to obtain the best filtering effect. Therefore, the side information used for selecting the structure element is coded using entropy coding and transmitted to the decoder. Through decoding by the morphological filter with the selected structure element, a filtered image with excellent quality is obtained. Simulation results demonstrate that the filtered image is enhanced by 0.95dB of PSNR.

Keywords: Morphological filter, Quad-tree Partition, DWT, ringing artifact, JPEG2000.

1 Introduction

The JPEG2000 image compression standard was introduced by the Joint Photographic Experts Group (JPEG) in 2000 as a replacement for the original JPEG encoding standard proposed in the early 1990s [1]. In contrast to the Discrete Cosine Transformation (DCT) technique used in the original standard, JPEG2000 employs a Discrete Wavelet Transformation (DWT) approach and therefore has a number of advantages, including a higher compression rate, an enhanced image quality and an improved region of interest (ROI) capability. However, JPEG2000 images require a greater decompression time than their JPEG equivalents and are prone to ringing artifacts around their edges when compressed using very low bit rates. For example, Fig. 1(a) and Fig. 1(b) show an original "Flash" image and the corresponding JPEG2000 reconstructed image for a coding rate of 0.078 bpp

(a) (b)

Fig. 1. Example of ringing artifacts in JPEG2000 coded image:
(a) original image, (b) reconstructed image (encoding rate: 0.078bpp).

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(bits per pixel). Comparing the two figures, it is clear that the reconstructed image lacks the crispness of the original and is characterized by obvious ringing artifacts. When encoding is performed at low bit rates, such artifacts occur irrespective of the filter bank chosen since the high-frequency components of the original image, which play an important role in smoothing ripple-like waveforms, are omitted and/or coarsely quantized during the wavelet-based encoding process in order to accomplish a low bit rate compression. In the image reconstruction process, the ultimate goal is to construct an image which replicates the original in every detail. As a result, it is necessary to remove the ringing artifacts in such a way that the smooth regions of the reconstructed image remain as smooth as those in the original, while the sharply defined edge features are retained (i.e. not smoothed) such that the aesthetic properties and appearance of the original image are preserved.

To reduce the ringing artifacts, many post-processing approaches have been proposed to alleviate the ringing artifacts either from the spatial domain or the frequency domain [2-15]. They attempt to adaptively filter each pixel in the image based on quantization parameter and neighboring information. Since large ringing artifacts are visible and will be mistaken as small features, they all have frequency components as features and are, therefore, not separable in the frequency domain. Hence, linear filters can seldom remove ringing artifacts without destroying the features simultaneously. Linear filters tend either to amplify the noise along the features or smooth out the ringing artifacts and undesirably blur the features at the same time. Linear filters always degrade edges, including boundaries and lines. In particular, they always blur edges. For example, median filters are very good at removing ringing artifacts from smooth areas, but they degrade thin lines and small edges. That is, median filters succeed in removing ringing artifacts but produce unacceptable blurred images. Since these filtering methods are pixel-by-pixel operations, they inevitably introduce undesired smoothing effects to non-artifacts pixels. Recent research has proposed morphological filter [4-8] to reduce the artifacts. In order to solve the ringing effect, a new scheme is proposed for the encoder and the decoder. Using the proposed DFQP for partitioning the original image, the then reconstructed image becomes more prefect because the partitioned image becomes differentiated between each block. Yen and Chen [4] proposed a de-ringing filter scheme. The designed filters first test the responses of the natural image and then selects the four best structure elements. Finally the selected structure elements are operated with dilation and erosion, and they become eight operations. As a result of doing the operation for the whole image before measuring the PSNR, the displayed response is the only one in the test step. Part of the image source includes the uncompressed image and the compressed image, and the edge information is detected by the Canny edge detector. Therefore, the compressed image is cut using the quad-tree partition, and eight morphological operations are applied to each block. The morphological operator is selected according to the result obtained from the sum of absolute difference.

This paper is organized as follows. Section 2 describes the DWT Feature Quad-tree Partition (DFPQ). Section 3 illustrates the 2D morphological filter design. Section 4 presents the main algorithm including the encoder and the decoder. Section 5 presents the simulation results. Section 6 is the conclusion.

2 DWT Feature Quad-tree Partition

In recent years, the DWT has been used widely in the transformation of spatial domain to frequency domain. In this paper, we employ a DFQP method to partition an image for pre-processing the compressed image. The output of the DFQP contains four subband blocks. According to frequency domain, the coefficients range form high to low of HH, HL, LH and HH respectively. For research purpose, the highest subband HH is considered for partitioning the similar image blocks because the subband shows directly related block variance. In addition, the summation of the HH subband coefficient is compared with the pre-setting threshold. If the summation is greater than the pre-setting, the image is cut into four sub-images. The process is applied to the other image blocks until the test is completed on the entire block. Fig. 2 shows the “Lena” image compressed at 0.096 bit per pixel cutting at 2452 blocks.

Due to the impartment property of ringing, transformation by DWT is considered. The Quad-tree (QT) partition is determined by the difference between the maximum and the minimum pixel value. The continuous and slighting change of the ringing does not result in a large variance, and is therefore not detectable. However, using the proposed DFQP, the ringing can be detected and the slighting change is completely is visible on the HH subband. This is the so called image block which needs cutting according to the summation of the high frequency coefficient.

Fig. 3 shows the line curve used the dimension scanning from (50, 484) to (210, 484) of the “Lena” image compressed at 0.096bpp. The slight wave is observable in the center, and because of the light difference, it is detectable by the proposed method of coefficient summation. Furthermore, we also compare the partition results between these two methods. Fig. 4(a) shows the result using quad-tree partition applied in the image “Lena”, and Fig. 4(b) shows the partition obtained using the appropriate DFQP method. From Fig. 4, it can be found that the DFQP is precisely partition an image to much smaller parts.

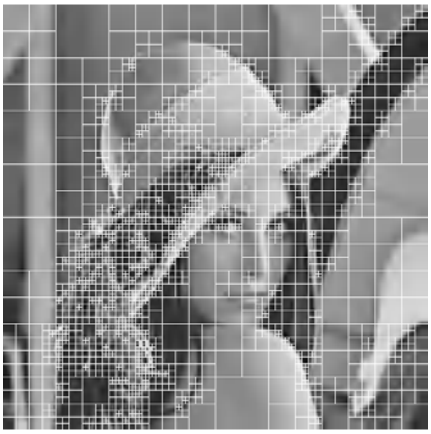


Fig.2. Lena image at rate 0.096bpp partitioned by DWT

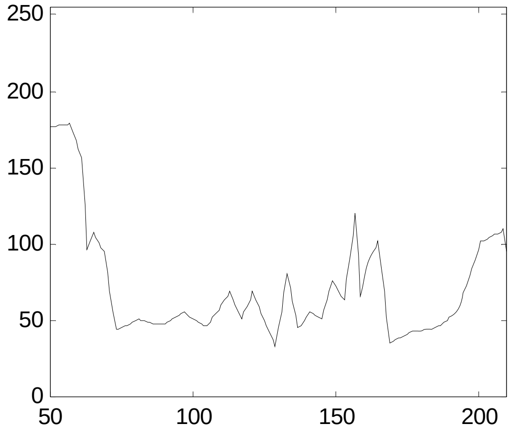


Fig. 3. Dimension scanning to Lena image from (50,484) to (210, 484)

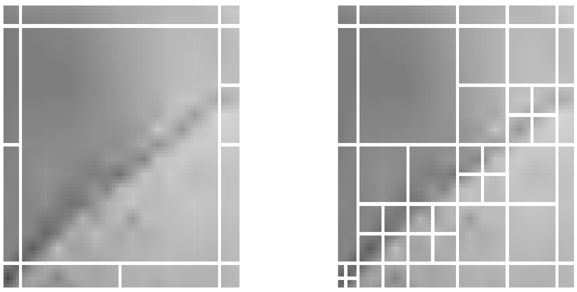


Fig. 4. Partition comparison between (a) Quad-tree partition and (b) DFQP

3 Two-Dimension Morphological Filter Design

The conventional morphological operation is Dilation and Erosion. Doing the operation needs to be collaborated with another element which is called structure element (SE). In the proposed method, the size of the structure element is 3×3 pixel. The structure of the SE shows in Fig. 5 where by "1" and "0" denote mask and unmask, respectively. The dilation and erosion operations can be expressed shown in Eq. (1).

$$(I \oplus S)(i,j) = \max\{I(i+x, j+y) | (x,y) \in S\}$$
$$(I \otimes S)(i,j) = \min\{I(i+x, j+y) | (x,y) \in S\} \quad (1)$$

where I and S denote the input images and the structure element, respectively. The concept of morphological operation is very simple, where a structure element is used to mask the center pixel, and the maximum or minimum pixel value is the output. For example, Fig. 6 is the resulting dilation operation using the SE in Fig. 5. In Fig. 6, the center pixel of the structure element is masked onto the target pixel. The resulting pixel values are "85", "89" and "91", and the subsequent output is the maximum pixel value of "91". Correspondingly, the output is "85" during the operation erosion.

4 Proposed De-ringing Algorithm

The proposed method is composed of an encoder and a decoder, and the overview flowchart is shown in Fig. 7. The input image data includes the original and compressed JPEG2000 images. The output is the filtered image, and S.I. denotes the coded information obtained by entropy coding. At the encoder, the compressed image is split into suitable size blocks, and the morphological operation is performed. The SE and the morphological operator

0	0	0
1	1	1
0	0	0

Fig. 5. 3*3 structure element

84	88	80	78	77
85	89	91	90	91
78	86	91	90	88
68	66	84	79	76
73	68	83	79	82

Fig. 6. An example of Dilation operation (Fig. 5 used as SE)

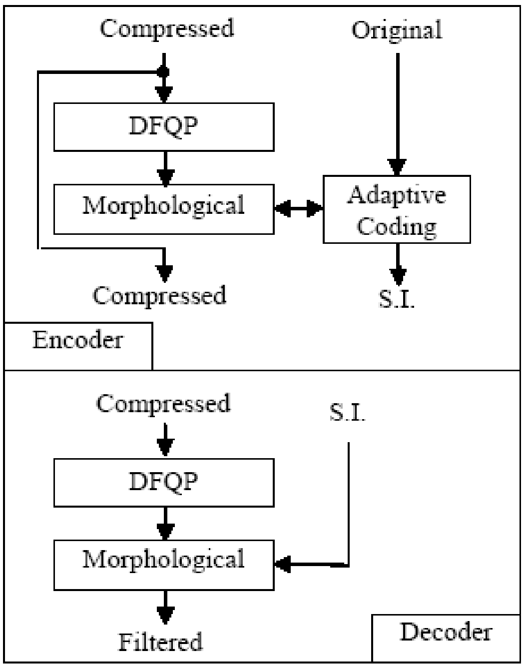


Fig. 7. The flowchart of proposed de-ringing algorithm

pair numbers are determined according to the operation results, thereby completing the encoder operation. At the decoder, the compressed image is split under identical condition. Since the partition conditions are same on both sides, the cutting order of the block is identical. Thus, by incorporating the morphology operation into the side information, the filtered image is obtained.

A detailed flowchart of the encoder is shown in Fig. 8(a), where the input parts include the compressed image, the original image, thresholds, and the number of the structure element. The coding procedures are as follows:

Step1: As shown in Fig. 1, after compression, the appropriate threshold value is applied to the compressed image which is then cut into proper blocks using DFQP.

Step2: Dilation and erosion are applied to each block using the SE number, SE_NUM (This SE_NUM parameter can be set by the user, default is 8).

Step3: Each computed block has a 2×SE_NUM computed image block. Using Eq. (2), the sum of the square difference (SSD) is calculated.

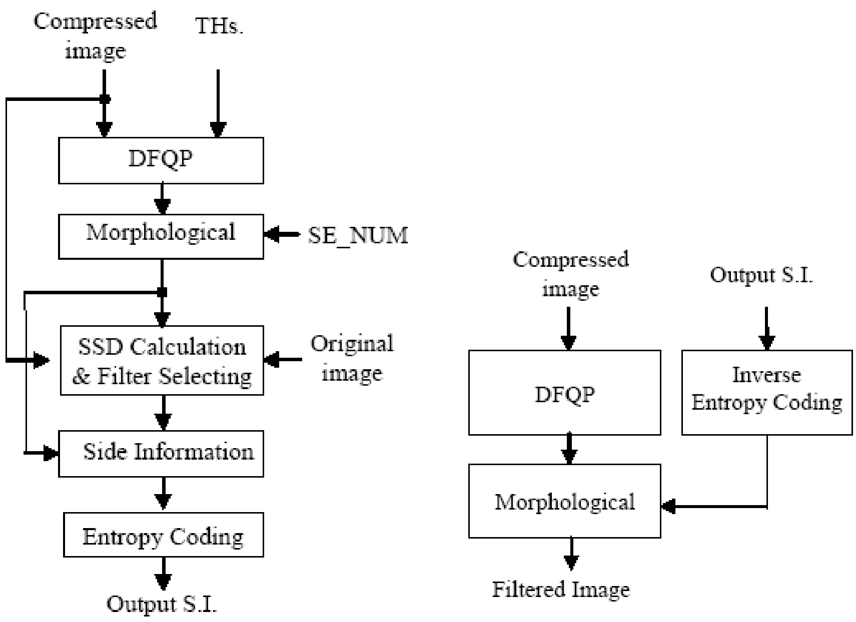
$$SSD(k)(s) = \sum_{i=0}^{HW}\sum_{j=0}^{HW}[x(i, j) - x_o(i, j)]^2 \qquad (2)$$

$$s = 0,1,\ldots,(SE\_NUM - 1)$$

In Eq. (2), x denotes the input image, x_o denotes the original image, HW expresses the size of the block, k expresses the serial number of the block, and s expresses the serial number of the filter. Subsequently, the SSD(k)(s) of every block can be obtained through the morphology operation. In addition, the square of error on each compressed image block, denoted by Unpro(k), is calculated and if the image quality can be thus improved , applied to every block after the morphology operation. The results of the calculations were statistically analyzed to select the best eight filters by summing all block's enhancement values.

Step4: Following the operation, there are twice the number of SE_NUM pieces of SSD value for every block, and the minimum SSD value is chosen such that it is greater than Unpro(k) in order to confirm the best eight filters. They are small because this block must be confirmed so that the image quality can be improved after the operation. For the k block, if the minimum (SSD (k) (s)) is smaller than Unpro(k), then s is the side information of this block.

Step5: The sequence filter numbers of the eight best filters are 0 to 7 in increasing order. The relationship shown in Table 1 is appended as the side information, and followed by entropy coding and output stream as illustrated below. Table 1 shows the relationship of the five image blocks (Block0~4) and eight selected filters. The Unpro and Filter0~7 denote the compressed and filtered SSD. For example, for the block 0 field, the minimum SSD is 40(filter 5), and since it is smaller than 141(Unpro), the output of side information of this block is "5". Accordingly, the side information for the other four blocks are 7, 0, 2 and 2 on the same condition.



(a) (b)

Fig. 8. The detail of the proposed algorithm in (a) the encoding procedure; (b) the decoding procedure

Table 1. Filter selection for De-ringing algorithm

	Block 0	Block 1	Block 2	Block 3	Block 4
Unpro	141	190	3012	634	693
Filter 0	143	211	1004	500	338
Filter 1	81	150	3406	732	502
Filter 2	78	130	2304	230	203
Filter 3	64	110	1894	405	210
Filter 4	122	210	3309	348	390
Filter 5	40	90	3401	834	450
Filter 6	89	190	1029	234	230
Filter 7	130	50	3023	501	478

Fig. 8(b) shows detailed flowchart of the decoder, which is sampler than the encoder. The input data includes the compressed image and the S.I. The decoding process is as follows:

Step1: The inverse entropy decoding side information from the S.I is utilized.
Step2: Using the same encoder condition for cutting, the compressed image forms the same image block sequence.
Step3: For every block, the corresponding SE and the morphological operator are selected to carry out the morphology operation. Upon completing all the block operation, the filtered image is obtained.

5 Experimental Results

In this section, we use the standard images to estimate and compare the performance for the proposed filter using the term of PSNR. Also, the proposed de-ringing filter will be compared with reference [4] under the same bit rate. The PSNR is defined as follows.

$$PSNR(dB) = 10 \times \log \frac{255^2}{(\frac{1}{M \times N})\sum_{i=1}^{M}\sum_{j=1}^{N}[x(i,j) - \hat{x}(i,j)]^2} \quad (3)$$

Where, M and N are the size of image. x(.) and $\hat{x}$(.) are pixels of original image and processes image, respectively.

In this paper, we employ a DFQP to pre-process the compressed image. Table 2 presented that the results obtained for the variation of the PSNR with the four compression bit rate for the Lena and Tiffany images, respectively. It can be seen that the DFQP partition method is superior to the QT partition method.

In the proposed method, the SE's number is eight, and therefore the morphological operators require sixteen filters. In this experiment, the test images "Lena" and "Tiffany" are compressed at four bit rates. Using the proposed method, the testing filter results are compared with [4] at the different bit rates. As shown in Table 3, for most of the compression rate, the comparison of hardware complexity obtained using the proposed method is better than [4]. In addition, Fig. 9 present the variation of the PSNR with the compression bit rate for the same image. Again, the results show that the proposed filter generally achieves a higher PSNR than the scheme proposed in [4]. Compared to the reference [4], the PSNR of the proposed method is beginning about 0.1 bpp, and the higher the bit rate, the more obvious the difference.

Fig. 10 illustrates the results obtained for the variation of the PSNR with the compression bit rate for the Lena and Tiffany images, respectively. In every case, it can be seen that the visual effect of the image "Lena", demonstrating the better filtering result obtained by the proposed filter.

Table 2. Performance comparison between QT and DFQP

Lena	QT		DEQP	
	PSNR	Total Bit-rate	PSNR	Total Bit-rate
0.046	27.35	0.087	27.455	0.087
0.080	29.757	0.130	29.882	0.129
0.096	30.613	0.148	30.720	0.147
0.149	32.379	0.200	32.557	0.200

Tiffany	QT		DEQP	
	PSNR	Total Bit-rate	PSNR	Total Bit-rate
0.046	28.634	0.082	28.711	0.082
0.080	30.398	0.105	30.502	0.105
0.096	30.902	0.123	31.018	0.123
0.149	32.283	0.178	32.391	0.178

Table 3. Comparisons of hardware complexity for various partition methods

	Qt	Canny	DFQP
Add	4	21	10
Sub	2	10	3
Multi		21	
Div		5	
Cmp	5	9	3
Shift	1	2	5
Sqrt		1	

6 Conclusion

This investigation has presented an adaptive morphological filter for the removal of ringing artifacts from reconstructed JPEG2000 images. Compared to the quad-tree partition, the proposed DFQP in this paper is a new and efficient partition method for cutting a wavelet compressed based image. This proposed method is based on selecting the best structure element and morphological operator. Experiment results show that the proposed method produced be more specific filtered results, and is therefore suitable for a high compressing rate image such as the JPEG2000 compression technology.

In the proposed filter presented in this study, the morphological filtering process is performed using just eight directional SEs. In a future study, the quality of the reconstructed image will be further enhanced by expanding this set of SEs to capture a greater range of edge orientations such that the ringing artifacts can be more effectively removed.

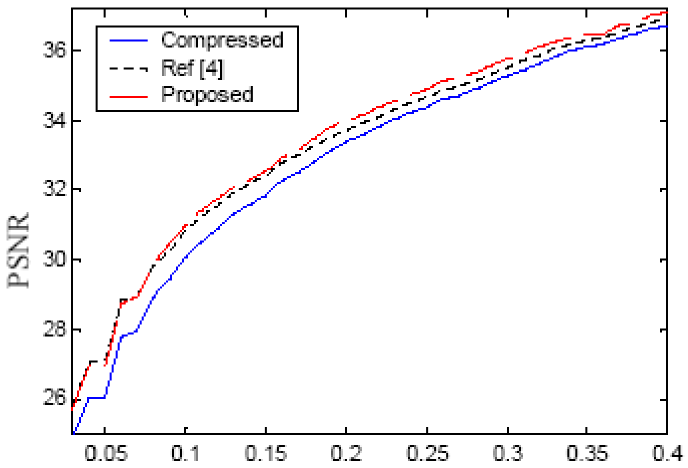


Fig. 9. Performance comparison in various bit rate for proposed, compressed, and Reference [4]

Fig. 10. Quality comparison; (a)Original image ;(b)compressed image; (c)filtered image used [4]; (d)filtered image used proposed method.

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