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Abstract

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ADAPTIVE FUZZY POST-FILTERING FOR HIGHLY COMPRESSED VIDEO

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ABSTRACT

This paper presents a newly developed adaptive fuzzy post-filter for removing blocking and ringing artifacts in the highly compressed images and videos. The proposed post-filter adaptively adjusts its filtering window size and the spread parameter in the fuzzy membership function according to the variance value in an edge map. The post-filtering operation is directly applied to the classified edge blocks in the image under the guidance of the edge map, while keeping smooth and textured blocks unchanged. The experimental results demonstrate that the proposed method possesses a good edge preserving property and can maximally remove coding artifacts. Compared with our previous method, the proposed post-filter achieves better objective and subjective quality and further reduces computational complexity.

1. INTRODUCTION

Post-filtering is a very useful and effective tool for suppressing coding artifacts in high compression applications and enhancing visual quality for image/video rendering. Many methods have been proposed for removing coding artifacts in decompressed images/videos [1][2][4][6]. However, these methods have been found to either introduce undesired blurring effects to the images or are unable to eliminate the artifacts sufficiently. MPEG-4 filtering method [1] achieves good results for de-blocking, but cannot successfully remove ringing artifacts. In our previous paper [8], we proposed a post-filtering scheme based on classification techniques for effectively reducing both blocking and ringing artifacts. Based on the local features, an edge map was constructed by using the local variance values. In the paper, a blocking artifact detection criterion and an adaptive 1-D filter for de-blocking were presented. Also, a fuzzy filter was introduced to suppress the ringing artifacts. The reason for choosing fuzzy filter was due to its edge preserving and clustering properties. In the previous experiments, a fixed spread parameter for fuzzy membership function and fixed window sizes, such as 3x3 or 5x5, were used in the de-ringing operation. The results showed that the post-filtering scheme under the guidance of the edge map is superior to the other reference methods.

In order to further increase the image quality and reduce the complexity, an adaptive fuzzy filtering with an improved inner edge block classification is proposed in this paper. The adaptation is for both window size and the spread parameter of the fuzzy membership function. Both image quality and processing speed are improved.

The rest of the paper is organized as follows: in section 2, a brief review of edge map guided fuzzy filtering will be given. In section 3, a detailed adaptation method will be presented. Experimental results will be given in section 4. Finally, section 5 will conclude the paper.

2. REVIEW OF EDGE MAP GUIDED FUZZY FILTERING

In our previous method [8], there are two classifications: pixel classification and 8x8 block classification. The pixel classification is performed by checking the variance values in the edge map according to a certain threshold criterion. A pixel can be classified as smooth pixel, edge pixel or texture pixel, corresponding to smooth regions, edges or texture regions, respectively. Based on the pixel classification, each 8x8 block can be classified as a smooth, edge or texture block. A block is determined to be an edge block if at least one edge pixel is present in the block.

Since ringing artifacts usually occur around the strong edges, the de-ringing operation skips all smooth and texture blocks and is applied to edge blocks only. Each pixel in the edge blocks is filtered by the fuzzy filter, which is derived from the fuzzy transformation theory [5][7]. In the fuzzy transformation, relationships between each spatial sample x_i (i is the spatial index) and each order statistic $x_{(j)}$ (j is the rank index and $x_{(1)} \le x_{(2)} \le ... \le x_{(N)}$) within an observation window are established through a real-valued fuzzy spatial-rank (SR) matrix, which is defined by

$$\tilde{R} = \begin{bmatrix} \tilde{R}_{1,(1)} & \cdots & \tilde{R}_{1,(N)} \\ \vdots & \ddots & \vdots \\ \tilde{R}_{N,(1)} & \cdots & \tilde{R}_{N,(N)} \end{bmatrix} \qquad (1)$$

where $\tilde{R}_{i,(j)} = \mu_{\tilde{R}}(x_i, x_{(j)}) \in [0,1], i, j = 1,2,...N,$ $\mu_{\tilde{R}}(a,b)$ is a membership function to compute the fuzzy relation between a and b with the following restrictions:

1. $\lim_{|a-b|\to 0} \mu_{\tilde{R}}(a,b) = 1$
2. $\lim_{|a-b|\to \infty} \mu_{\tilde{R}}(a,b) = 0$
3. $|a_1 - b_1| \le |a_2 - b_2| \Rightarrow \mu_{\tilde{R}}(a_1,b_1) \ge \mu_{\tilde{R}}(a_2,b_2)$

A Gaussian function $\mu_G(a,b) = e^{-(a-b)^2/2\xi^2}$ is used as the membership function, where the spread parameter $\xi = 20$. Since the element values are dependent on the distance between each pair of samples, the fuzzy SR matrix contains the spread information embedded in the observation samples. The original (crisp) spatial samples can be "transformed" into fuzzy spatial samples by multiplying the crisp order statistics vector with the row normalized fuzzy SR matrix. The output of the fuzzy filter is just the fuzzy counterpart of the center sample in the observation (filtering) window, which can be obtained using the following simplified formula:

$$y = \tilde{x}_c = \frac{\sum_{j=1}^{N} x_{(j)} \mu_{\tilde{R}}(x_c, x_{(j)})}{\sum_{j=1}^{N} \mu_{\tilde{R}}(x_c, x_{(j)})}, \qquad (2)$$

where x_c and $\tilde{x}_c$ are crisp and fuzzy center sample, respectively. The above formula indicates that the fuzzy filter has the property of clustering the similarly valued samples around their local mean and leaving edge samples unchanged. Therefore, the fuzzy filter preserves the strong edges while removing weak ones associated with annoying ringing artifacts. By applying fuzzy filter to the edge blocks only, unnecessary smoothing effects are avoided.

3. EDGE MAP GUIDED ADAPTIVE FUZZY FILTERING

It can be seen from the above formula (2) that the fuzzy center sample is a weighted average. Each weight is given by the Gaussian membership function, in which the spread parameter ξ plays an important role. The spread parameter controls the Gaussian function shape (filtering coverage); with large ξ, the Gaussian curve becomes fat corresponding to the strong smooth filtering; with small ξ the Gaussian curve becomes sharp corresponding to the weak smooth filtering. The filtering window size has a similar characteristic: while a large window corresponds to a strong smooth effect, a small window corresponds to a weak smooth effect.

In view of the analysis of the above factors, we propose an adaptive fuzzy filtering scheme in this paper. The window size and the spread parameter ξ are determined adaptively according to the variance values in the edge map. There are four combinations of window size and spread parameter: small window with small ξ; small window with large ξ; large window with small ξ; and large window with large ξ. In this paper, two combinations are shown. The basic rule is that small variance corresponds to a small window and small ξ; large variance corresponds to a large window and large ξ.

Figure 1 shows the adaptation diagram for the proposed adaptive fuzzy filtering. The input is a classified edge block and a decompressed image block. Now, a block is defined as an edge block if there are at least eight edge pixels existing in the block. Checking the variance values in the edge block, if a variance value is greater than 22, it is certain that the corresponding image pixel is on the edges. Therefore, in order to retain the edge sharpness, this pixel should not be filtered. Unlike our previous method, every pixel within the edge block gets filtered.

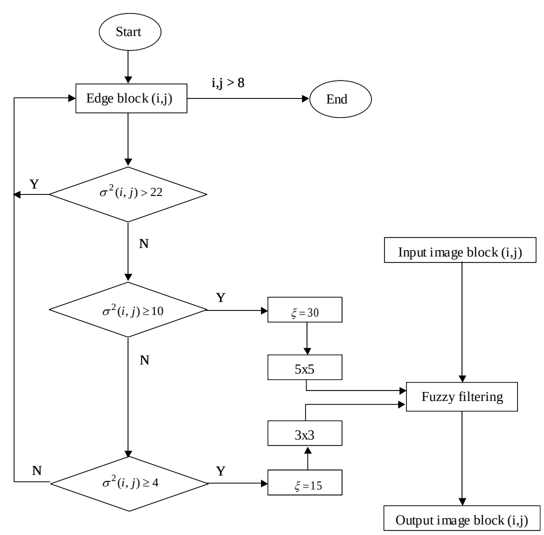

Figure 1. Adaptive fuzzy filtering.

If the variance value in the edge block is less than 22 and greater than or equal to 10, it is most likely that the image pixel is corrupted by the ringing noise. Thus, a large spread parameter $\xi = 30$ is used in the fuzzy membership function simultaneously with a large 5x5 window to maximally eliminate the ringing artifacts. If the variance is less than or equal to 10 and greater than or equal to 4, this suggests the image pixel may be in the weak edges area or may be slightly corrupted by the ringing noise. In this case, a small spread parameter $\xi = 15$ and a small 3x3 window are used for weak smooth filtering. Otherwise, if the variance is less than 4, the image pixel must be in a homogeneous region, there is no need to do the filtering.

4. EXPERIMENTAL RESULTS

The proposed adaptive fuzzy filter has been tested on several video sequences. Mobile Calendar and News are used for the evaluation. The Mobile sequence has resolution of 720x576 (interlaced), while the News sequence has 352x288 (progressive). Both sequences are encoded using MPEG-2 TM5 encoder. The coding conditions are N=15, M=3, using fixed Q-scale, which is 60 for all frame types. The total number of frames is 100 for Mobile and 150 for News.

In the previous paper [8], a comparison between our previous edge map guided fuzzy filtering method and four most referenced methods was given. In order to demonstrate the advantages of the adaptive fuzzy filtering, only results for the proposed method and our previous method are listed in this paper for the comparison. These results are shown in Table 1. It can be seen that the proposed method not only achieves better image quality, but also achieves a significant improvement in processing time, which is critical for practical applications.

Table 1. PSNR and Processing time comparison

Sequences	Old PSNR (dB)	New PSNR (dB)	Old Processing Time (sec)	New Processing Time (sec)
Mobile	25.26	25.56	149.97	52.27
News	30.61	30.93	31.31	14.14

Old: Edge map guided fuzzy filter
New: Edge map guided adaptive fuzzy filter

The subjective results for a portion of the Mobile sequence and a portion of the News sequence are shown in Figure 2. In the figure, (a1) and (b1) are the decompressed images, (a2) and (b2) are the results obtained from the previous edge map guided fuzzy filtering, and (a3) and (b3) are the results obtained from the proposed edge map guided adaptive fuzzy filtering. It is evident from the subjective results that the proposed adaptive method preserves more edge and detailed information than the previous method. For example, the little pig faces in Mobile sequence and the man's face features in News sequence, such as nose, eyes and mouth etc. are maximally retained while the ringing artifacts are removed.

In the experiments, two window sizes for de-ringing are 3x3 and 5x5 and two spread parameters are 15 and 30. The window size and the spread parameter are optimally determined under the guidance of the edge map. Moreover, since further classification is performed within the edge blocks, a large amount of unnecessary filtering is avoided.

5. CONCLUSIONS

In this paper, an edge map guided adaptive fuzzy post-filtering scheme has been presented. Based on the classification of visual artifacts, adaptive 1-D low-pass and 2-D adaptive fuzzy filters are applied to the classified blocks to remove blocking and ringing artifacts. The experimental results demonstrate the superior improved performance of the proposed method compared to our previous method.

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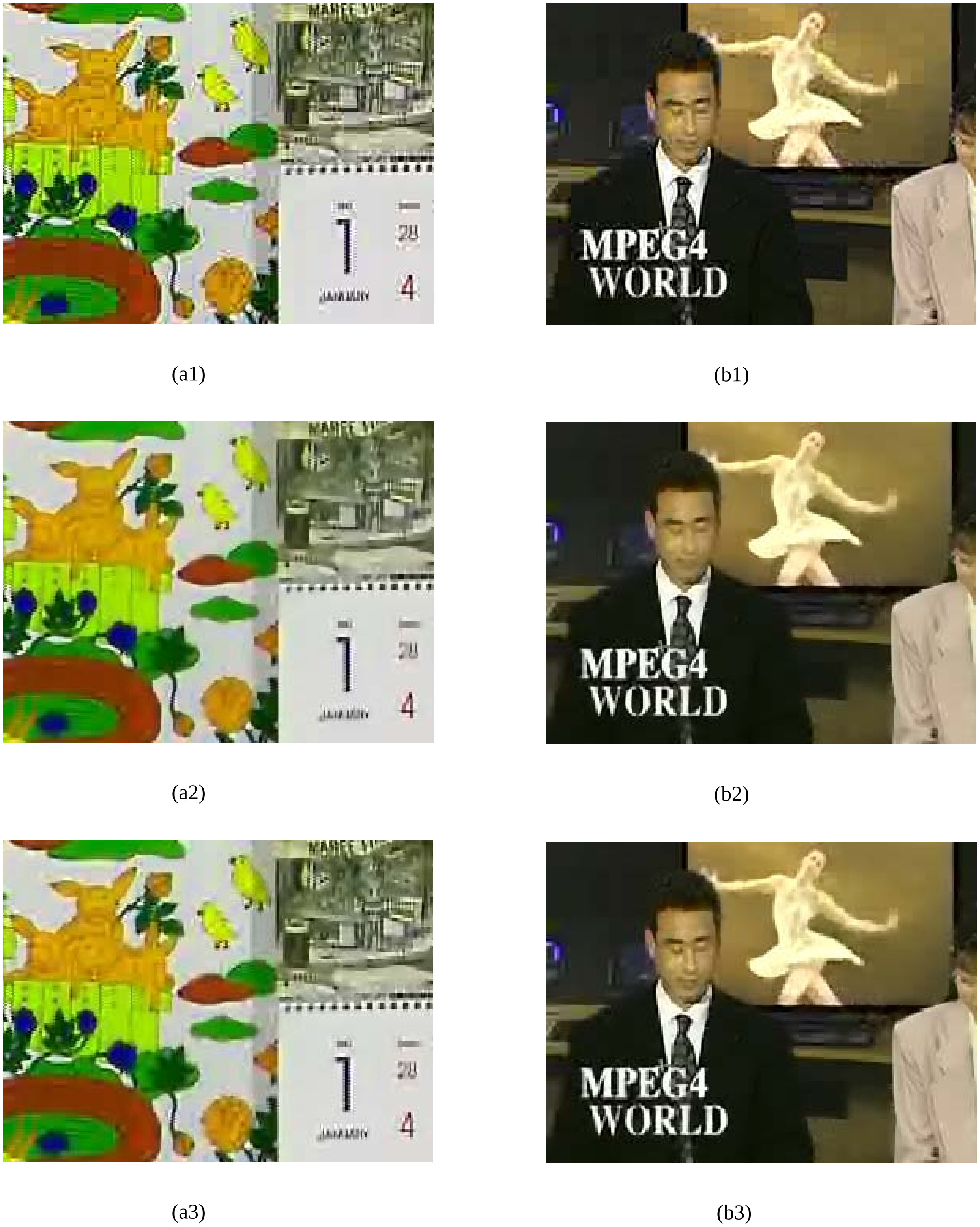

Figure 2. Subjective results from a portion of the Mobile sequence and a portion of News sequence: (a1), (b1) are decoded images, (a2), (b2) are the results from edge map guided fuzzy filter, and (a3), (b3) are the results of proposed edge map guided adaptive fuzzy filter.