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# EDGE-BASED DIRECTIONAL FUZZY FILTER FOR COMPRESSION ARTIFACT REDUCTION IN JPEG IMAGES

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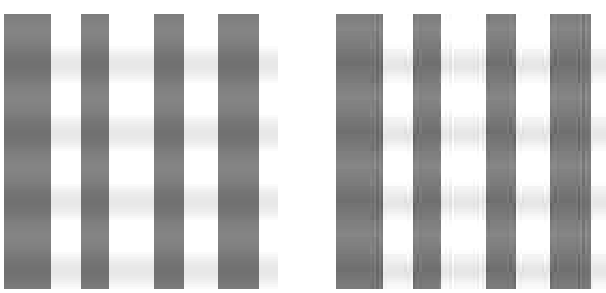
**ABSTRACT**

We propose a novel method to reduce both blocking and ringing artifacts in compressed images and videos. Based on the directional characteristics of ringing artifacts along edges, we use a directional fuzzy filter which is adaptive to the direction of the ringing artifact. The filter exploits the spatial order, the rank order and the spread information of the signal together with the position of the pixels to enhance the quality of the compressed image. Simulations results on compressed images and videos having simple and complex edges show the improvement of the proposed directional fuzzy filter over the conventional fuzzy filtering and other approaches.

***Index Terms—*** fuzzy filter, image enhancement, ringing artifacts, blocking artifacts.

## 1. INTRODUCTION

Compressed images suffer from ringing and blocking artifacts. Separately compressing each block will break the correlation between pixels at the border of neighboring blocks and cause blocking artifact. Ringing artifacts occur due to the loss of high frequencies when quantizing the DCT coefficients with a coarse quantization step. Ringing artifacts are similar to the Gibbs phenomenon [1] and most prevalent along the edges of the image. An example of these artifacts is shown in Fig. 1 where ringing is seen along the vertical edges of the image; blocking artifacts are also visible at the border of $8 \times 8$ blocks in this JPEG image as well.



(a) Original image (b) JPEG image ($39.77dB$)

**Fig. 1**. An example of JPEG artifacts.

Many filter-based denoising methods have been proposed to reduce these artifacts. For blocking artifact reduction, a linear low-pass filter was used in [2] to remove the high frequencies caused by blocky edges at borders, but excessive blur was introduced since the high frequencies of the image are also removed. In [3], [4] and [5], low-pass filters were applied to the DCT coefficients of shifted blocks. In particular, the adaptive linear filters in [4] and [5] were proposed to overcome the problem of over-blurring the images, but these methods require high complexity processing and a classification step. To reduce ringing artifacts, the methods in [6], [7] and [8] propose to first detect the areas with ringing artifacts near strong edges, then apply linear or nonlinear isotropic filters to reduce the ringing artifacts.

Non-linear filters help preserve edges of the images by exploiting the spatial order of the surrounding pixels together with rank order. Examples include median filtering [9],[10], and fuzzy filtering [8],[11]. These filters have shown to be effective in denoising both blocking and ringing artifacts while retaining the sharpness of real edges. One drawback of fuzzy filters for multi-dimensional signals such as images is that the signal is converted to a vector before filtering. The relative position of the pixels is ignored in these cases.

While blocking artifacts are always either vertical or horizontal, ringing artifacts are along the edges of arbitrary direction. Thus it is expected that deringing performance would improve if the filter is applied adaptively according to the direction of the edges. We propose a directional fuzzy filter, which accounts for the relative position of pixel samples to control the strength of the fuzzy filter. The paper will be organized as follows. Section 2 of this paper provides background on fuzzy filtering and introduces the concept of a directional filter. Section 3 describes an edge-based scheme that realizes the directional fuzzy filtering concept. Simulation results that compared the proposed directional filter to existing approaches are presented in Section 4. Concluding remarks are given in Section 5.

## 2. DIRECTIONAL FUZZY FILTER

Fuzzy filters, such as those described in [8] and [11], improve on median filters [9] or rank condition rank selection filters [10] by replacing the binary spatial-rank relation by a real-valued relation. This permits the filter to be adaptive to the spread of the signal: averaging the flat areas while keeping the isolated pixels in the edge areas. Assume that $I(m,n)$ is the center pixel of a $M \times N$ window, its equivalent raster scan vector is $I_l = [I_1, \ldots, I_{K=MN}]$ and its order statistic vector is $I_L = [I_{(1)}, \ldots, I_{(K)}]$ where $I_{(i)} \leq I_{(j)}$ if $i \leq j$, the relation between $I_l$ and $I_L$ is formulated by a linear transformation

$$I_L = I_l \times R \qquad \text{and} \qquad I_l = R^T \times I_L \tag{1}$$

where $R$ is the spatial-rank matrix in which each element

$$R(i,j) = \mu(I_i, I_{(j)}) \tag{2}$$

*This work was performed while Dũng T. Võ was with Mitsubishi Electric Research Laboratories is the membership function. Real-valued membership functions have to satisfy the following constrains:

1. $\lim_{|a-b|\to 0} \mu(a,b) = 1$,
2. $\lim_{|a-b|\to \infty} \mu(a,b) = 0$,
3. $\mu(a_1, b_1) \geq \mu(a_2, b_2)$ if $|a_1 - b_1| \leq |a_2 - b_2|$.

This means that the relation between two samples increases as the distance between them decreases. Widely used membership functions include uniform, Gaussian and triangular functions. The Gaussian membership function is defined as,

$$\mu_G\big(a,b\big) = e^{-\frac{(a-b)^2}{2\sigma^2}} \qquad (3)$$

where $\sigma$ is the spread parameter controlling the strength of fuzzy filter. The reconstructed pixel will be calculated by the fuzzy counterpart of the center sample in the window

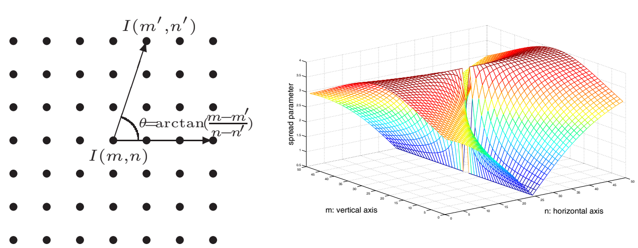
$$\hat{I}(m,n) = I_{\left(\left[\frac{K}{2}\right]\right)} = \frac{\sum_{i=1}^{K} \mu_G\big(I_{\left[\frac{K}{2}\right]}, I_{(i)}\big) \times I_{(i)}}{\sum_{i=1}^{K} \mu_G\big(I_{\left[\frac{K}{2}\right]}, I_{(i)}\big)} = \frac{\sum_{i=1}^{K} \mu_G\big(I(m,n), I_i\big) \times I_i}{\sum_{i=1}^{K} \mu_G\big(I(m,n), I_i\big)} \qquad (4)$$

where $\left[\frac{K}{2}\right]$ is the nearest integer number greater than or equal to $\frac{K}{2}$. It is evident from (4) that $\mu_G\big(I(m,n), I_i\big)$ is the weight of the nonlinear filter. This weight is exponentially and inversely proportional to the difference $|I(m,n) - I_i|$. If $I_i$ is very different than $I(m,n)$, its contribution to the output which is presented by the weight $\mu_G$ is small. This explains the edge preservation characteristic of the fuzzy filter. High $\sigma$ values will average the signal while small $\sigma$ values will keep the signal isolated.

In conventional fuzzy filtering, the spread parameter is constant for all directions. In our proposed approach, $\sigma$ is directionally adaptive. This is achieved by using the angle $\theta$ between the pixels as defined in Fig. 2(a) to control the spread parameter directionally. For the example, in Fig. 1, the filter should ideally apply a stronger smoothing in the horizontal direction, where the ringing artifacts are likely to have no relation with the original value, and a weaker filtering in the vertical direction, which is the edge direction of the image. One general form of cosine-based spread parameter which satisfies this requirement is

$$\sigma(\theta) = \sigma_m \big(\alpha + \beta\,|\cos(\theta)|\big) \qquad (5)$$

where $\sigma_m$ is the amplitude of the spread parameter, $\alpha$ and $\beta$ are positive scaling factors which control the maximum and minimum strength of the directional filter.



(a) Angle $\theta$ (b) Spread parameter

**Fig. 2**. Angle and spread parameter for directional fuzzy filter.

For enhancing the quality of the JPEG images in Fig. 1(a), parameters in (5) are experimentally chosen as $\sigma_m = 15$, $\alpha = 0.5$ and $\beta = 3.5$. Comparing to the isotropic spread parameter $\sigma = 15$, this directional spread parameter which is plotted in Fig. 2(b) attains minimum value $\sigma_{min} = \alpha\sigma_m = 7.5$ for vertical direction and the maximum value $\sigma_{max} = (\alpha+\beta)\sigma_m = 60$ for horizontal direction. Fig. 3 shows the result of the enhanced images with both the conventional and directional fuzzy filter. Compared to the compressed image in Fig. 1(b) (39.77 dB), the enhanced image using the conventional fuzzy filter in Fig. 2(a) (45.53 dB) and the enhanced image using the directional fuzzy filter in Fig. 2(b) (47.82 dB) achieve significant improvement in visual quality and PSNR. This shows the effectiveness of fuzzy filter in reducing both blocking and ringing artifact. It also demonstrates the basic merit of the directional fuzzy filter to more substantially reduce the ringing artifacts compared to isotropic fuzzy filtering. The PSNR improvement of the directional fuzzy filter over the conventional fuzzy filter is 2.29 dB.

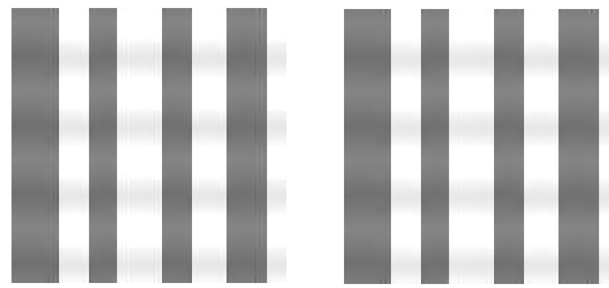

(a) Isotropic ($45.53dB$) (b) Directional ($47.82dB$)

**Fig. 3**. Result of using fuzzy filter.

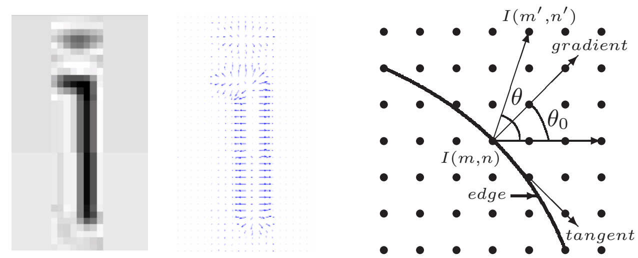
## 3. EDGE-BASED DIRECTIONAL FUZZY FILTER

For real images with more complicated edges, the ringing artifacts occur along the edges and we apply the strongest filtering in the direction perpendicular to the edge. We use the gradient to indicate the direction of the spread parameter. The edges are detected by Sobel operator with horizontal and vertical derivative approximation of the gradient $G_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix} \times I$ and $G_y = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix} \times I$. The gradient magnitude is calculated by $G = \sqrt{G_y^2 + G_x^2}$ and its direction by $\theta_0 = atan\big(\frac{G_y}{G_x}\big)$. The gradient for the region of the mobile sequence shown in Fig. 4(a) is shown in Fig. 4(b). The spread function in this case is determined by the angle $(\theta - \theta_0)$ instead of $\theta$ in (5), where the angles $\theta$ and $\theta_0$ are defined as in Fig. 4(c). This spread parameter should also be adaptive to different areas which have different activity levels such as smooth or detail areas. We use the standard deviation $STD(I(m,n))$ of pixels in the window $W$ centered on $I(m,n)$ to control the amplitude of spread parameter $\sigma_m$ in (5) as

$$\sigma_m(m,n) = \sigma_0 \left( (1-\gamma) \times \frac{STD(I(m,n)) - STD_{min}}{STD_{max} - STD_{min}} + \gamma \right) \qquad (6)$$

where $STD_{max}$ and $STD_{min}$ are respectively the maximum and minimum value of all $STD(I(m,n))$ values in the current frame. $\sigma_m$ is scaled to $[\gamma\sigma_0 \quad \sigma_0]$ so that the fuzzy filter is still applied with $\sigma_m = \gamma\sigma_0$ to the lowest activity areas.

The proposed algorithm for the directional fuzzy filtering based on edge data is shown in Fig. 5. The pixels are first classified into edge pixels and non-edge pixels by comparing the gradient magnitude to an empirically determined threshold. Edge pixels which are isolated from surrounding pixels can be processed using the isotropic




(a) JPEG image (b) Gradient (c) Angle $\theta$ and $\theta_0$

**Fig. 4**. Edge-based directional fuzzy filter.

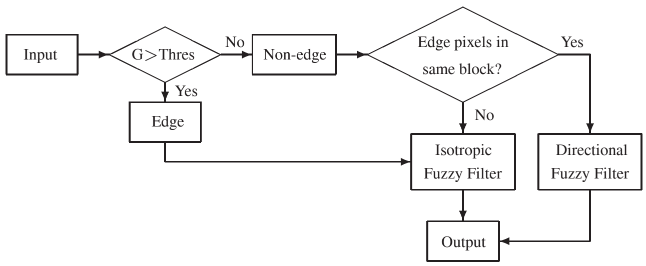



**Fig. 5**. Flow chart of the directional fuzzy filter.

fuzzy filter. For non-edge pixels, the algorithm then checks whether or not there are any edge pixels in the same block. If not, the ringing artifacts in this block are not considered to be oriented in any particular direction and the non-edge pixel will be filtered with an isotropic fuzzy filter. For the remaining non-edge pixels, the nearest edge pixel within the same block is located and used to determine the tangent angle of the edge pixel, which is then used to control the spread parameter. The fuzzy filter will apply less smoothing in the tangent direction and greater smoothing in the direction perpendicular to the tangent.

## 4. SIMULATION RESULTS

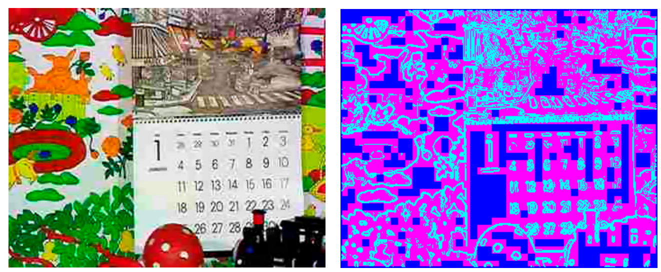
To demonstrate the effectiveness of the directional fuzzy filtering scheme, simulations that compare the proposed scheme to existing schemes are performed. The quality of the different approaches is compared in terms of visual quality and PSNR. For comparison, the denoising methods proposed by Chen [4], Liu [5] and Kong [8] are also simulated. In our experiments, a 1D fuzzy deblocking filter as in [8] is applied prior to the proposed directional fuzzy deringing-filter. Only the non-edge pixels that have $G > 210$ are filtered to avoid destroying the real edges of the image. The same values of spread parameters in Section 2 are used for this simulation. The window size $W$ is $5 \times 5$ and $\gamma = 0.5$ so that the spread parameter for the lowest activity areas is half of that for the highest activity areas. We compressed several CIF resolution video sequences using motion JPEG with scaling factor of 4. The test images are the frames taken from Silent, Foreman, Mobile, Paris, News and Mother sequences.

Fig. 6(a) shows the deblocked image for $4^{th}$ frame of Mobile sequence and its classification map for directional deringing in Fig. 6(b). In this map, the cyan pixels are edge-pixels, magenta pixels are non-edge pixels which will be directionally filtered and blue pixels are non-edge pixels which will be isotropic filtered as with edge-pixels. Table 1 summarizes the average PSNR results for all of the sequences when different enhancement techniques are applied. These numerical results show that the directional fuzzy filter provides higher PSNR improvement over existing techniques including the conventional fuzzy filter that employs isotropic filtering. Further

**Table 1**. Comparison of PSNR in units of $dB$

| Sequences | JPEG | Chen | Liu | Conventional Fuzzy | Directional Fuzzy |
|---|---|---|---|---|---|
| Silent | 27.84 | 28.37 | 28.33 | 28.33 | **28.56** |
| Foreman | 28.06 | 28.46 | 28.41 | 28.78 | **28.90** |
| Mobile | 21.22 | 20.96 | 21.13 | 21.50 | **21.52** |
| Paris | 23.38 | 23.25 | 23.31 | 23.80 | **23.85** |
| News | 27.48 | 27.58 | 27.55 | 27.94 | **28.03** |
| Mother | 31.02 | 31.83 | 31.62 | 31.77 | **32.01** |
| Average gains | | 0.2433 | 0.2267 | 0.5200 | **0.6450** |

simulation results which are not included due to limited space also show that the proposed directional fuzzy filter improves PNSR on every frame throughout the sequences and provides uniform gains over existing techniques. Also the consistent improvements over all the test sequences indicate that the chosen filtering parameters are adequate and relatively insensitive to the contents of video.



(a) Deblocked image (b) Pixel classification of (a)

**Fig. 6**. Pixel classification for directional filtering.

To evaluate the visual quality, both full frame and zoomed views are provided for original frame (Figs. 7(a),(b)), compressed frame (Figs. 8(a),(b)) and enhanced frames in Figs. 8(c) -(j). It is evident from these sample results that the DCT-based lowpass filtering technique proposed by Chen is able to suppress some of the ringing artifacts, but it introduces a substantial amount of blur in the processed image. Liu's method is able to retain some of the sharpness, but is not able to reduce the ringing artifacts effectively. The conventional fuzzy filter shows much less ringing around the edge, especially within the calendar area, while the directional fuzzy filter is able to reduce the ringing artifact even further. It is clear from these visual results that the directional fuzzy filter offers the best quality. It is able to further reduce ringing over the conventional fuzzy filtering approach and outperforms other existing denoising techniques. The improvement in visual quality of directional fuzzy filter over other methods is also consistent when displayed as a video sequence with less mosquito artifacts.

## 5. CONCLUSIONS

We propose an effective algorithm for image and video denoising using a directional fuzzy filter. The proposed method overcomes the limitations of conventional nonlinear filters by accounting for the relative position of pixels. It is shown that the proposed directional fuzzy filter improves both visual quality and PSNR of compressed images and video compared to existing approaches.

It is also noted that the proposed directional fuzzy filter could also be combined with the temporal filtering approach described in [12]. One simple possibility for such a combined scheme would be to follow the deblocking and temporal filtering with the proposed directional filtering filter described in this paper. A more sophisticated treatment of directional characteristics over both space and time is a topic for further study.

(a) Original frame (b) Zoomed version of (a)

**Fig. 7**. Original frame of Mobile sequence.

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(a) Compressed image (b) Zoomed version of (a)

(c) Chen's method (d) Zoomed version of (c)

(e) Liu's method (f) Zoomed version of (e)

(g) Conventional fuzzy filter (h) Zoomed version of (g)

(i) Directional fuzzy filter (j) Zoomed version of (i)

**Fig. 8**. Comparison of filter results.