Removal Of Gaussian Noise Using Edge-Based Bilateral Filter

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Abstract— This paper presents the removal of Gaussian noise using Edge based bilateral filter. All the pixels of a noisy image are classified into edge region or non-edge region and the different strategies and factors are adopted in the edgebased bilateral filter to maintain the features of image and at the same time the noise level is reduced. The experimental results are shown that this filter achieves very good performance in restoring real noisy images compared with other denoising algorithms.

Keywords— Edge-based bilateral filter; Image restoration; Real noisy image; Edge Detector.

1. INTRODUCTION

When the images are transmitted, it is often corrupted by Gaussian type noise. In order to reduce the effect of the noise, many denoising methods have been developed over the past years, in which the wavelet threshold is one of the most popular approaches [1]. Accurate and efficient wavelet coefficients modeling, whether done directly or indirectly, is a complex component of image denoising. In [2], the Gaussian density is used to model the wavelet coefficients, and for coefficient variances, the locally adaptive Wiener estimates were used. [3] presented Gaussian scale mixture model and Bayesian least squares estimator in the wavelet domain. In [4] the dependency among the wavelet coefficients are considered and Non-Gaussian bivariate distributions were introduced. In [5] a new wavelet-based noise reduction algorithm which used both enhanced directional wavelet bases and multivariate shrinkage method was introduced.

The main problem of wavelet-based methods is that they are prone to produce salient artifacts such as the low frequency noise and the edge ringing related to wavelet hidden. By combining different domains, Some denoising methods achieve more satisfactory results with fewer artifacts. Dabov et al. grouped two-dimensional (2D) applied a collaborative filtering procedure that consisted of the 3D transformation, shrinkage of the transformed spectrum (BM3D) [6]. And in [7], by incorporating wavelet-based trivariate shrinkage filter with a spatial-based joint bilateral filter, we have proposed an efficient denoising algorithm. Although mentioned algorithms produced high-quality restored image with the additive white Gaussian noise, they did not perform effectively for real noisy images. It is well known that the assumption of the white Gaussian noise is not always accurate in real noisy images.

The overall Non-Gaussian noise characteristics in a real image depend on many factors, which, in general, are the space varying and channel dependent. In fact, the real noisy images restoration is rather difficult to realize. A noise adaptive spatio-temporal filter for removal of noise in low light level images was presented in [8]. The neighborhood-based bilateral filter [9] is often used for removing the Non-Gaussian noise. Multiresolution bilateral filter (MBF) was introduced [10], the bilateral filtering was applied to the approximation subbands of a signal decomposed using a wavelet filter bank. Multistage noise filtering with edge enhancement approach, which integrated bilateral filter and edge detection, has been presented in [11]. But these neighborhood-based bilateral filters are hard to preserve the image structure when removing the noise. In [12] and [13], Buades et al. extended the neighbourhood filters to a wide class which they called non-local means (NLmeans). In order to search the self-similarity, the neighborhood was defined by the grey level distance of the block, and the spatial constraint was relaxed.

The success of BM3D [6] is also partly due to use the non-local means in grouping 2D image fragments. An adaptive nonlocal-means algorithm for image denoising was proposed in [14]. It employed the singular value decomposition method and the K-means clustering technique to achieve robust block classification in noisy images. There are, however, two main problems for the non-local means algorithms: how to group the neighborhood efficiently in the edge region and remove the noise in the non-edge region. Combining the bilateral filter and the non-local means algorithm is one way to improve the restore performance for the real noisy images. An efficient edge-based bilateral filter is designed to overcome the shortcomings of the two methods.

All the pixels of a noisy image are classified into edge region or non-edge region and the different strategies and factors are adopted in the edgebased bilateral filter to maintain the features of image and at the same time the noise level is reduced. In the edge region, it is first to consider preserving the image features, and to use the nonlocal bilateral filter.

Based on three factors, the edge direction, the edge magnitude and the block distance non-minimal suppression, this filter can group the similar neighbours efficiently. And in the non-edge region, reducing the noise level is more important, and local neighborhood-based bilateral filter is used. Extensive experimental results are shown that this filter is performed well in restoring real noisy images corrupted by Non-Gaussian noise.
2. EDGE-BASED BILATERAL FILTER

A. Bilateral Filter and Edge Detector

The bilateral filter, as described in [9], was applied as a simple nonlinear filter to remove noise. For given a noisy image $u$, at a pixel location at point $(i, j)$, the restored result can be directly calculated by a weighted average of the intensities in its noisy neighbourhood. The edges carry important information of the images, and the edge detection is one of the most often used techniques in the digital image processing. In [11], the edge detection stage with a Sobel operator which was presented in the early years. The Canny edge detector [15] has been widely used in the grayscale image edge detection. The main reason is that after the edge extraction, the non-maximal suppression and the hysteresis threshold can produce thin and well connected edge map. Unlike the thin edge map as Canny edge detector, in this paper, to cooperate with the bilateral filter, the edge detector divide all pixels of a noisy image into the edge region or the non-edge region as shown in Fig. 1(c). So after edge extraction, the hysteresis threshold is used directly as a means of producing more connected edge region. Two thresholds are chosen, i.e., $T_1$ and $T_2$ for the high and the low one, respectively. If the edge magnitude of a pixel is larger than $T_1$, it is presumed to be an edge pixel, and is marked and any pixels, which connected to this edge pixel and the edge magnitude are greater than $T_2$, are also selected as the edge pixels.

![Block diagram of edge based bilateral filter](image)

B. Non-local bilateral filter in the edge region

In the edge region, it is first to consider preserving the image features. As mentioned above, the non-local means algorithm uses the image self-similarity to preserve the image features. The neighborhood similarity is defined by the block distance, which is calculated by the L2-distance between the central block and the candidate block in a large area.

Instead of sliding by the central block to every candidate blocks, only the block that has similar edge direction with the central block is considered. The non-maximal suppression is used along with Canny edge detector to give a thin and sharp edge map before the hysteresis threshold. The image edge magnitude is scanned along the edge direction, only the local maximal is considered in next hysteresis threshold. In order to select the most similar blocks that conserve the image features, the non-minimal suppression and the constraint of the distance are imposed to the candidate blocks. Only the candidate blocks, which the distance is local minima and satisfy the constraints, are selected as similar neighbors in the non-local bilateral filter.

C. Local bilateral filter in the non-edge region

In the non-edge region, it is important to reduce the noise level, and local neighborhood-based bilateral filter is used. The local edge stopping function is defined for the non-edge region: Compared with the edge stopping function of the bilateral filter described in Section 2.1, it is only consider the set of the non-edge pixels located in the adaptive spatial window restoring the central pixel at $(i, j)$. If all the pixels in the small window are the non-edge, then the larger window is used to smooth the noise. Otherwise, the smaller is applied to smooth the image detail parts, if the central pixel is near the edge.

3. THE DENOISING ALGORITHM

For convenience, the denoising algorithm is summarized and listed as follows.

1. Input a noisy image $u$, and set $k=1$;
2. For each channel of $u$, the edge-based bilateral filter is used shown in Fig. 2;
3. Set $k=k+1$. If $k=2$, let $u=\tilde{u}$ and return to step 2; otherwise stop iteration and get restored image $\tilde{u}$.

It is noted that two iterations are considered for improving the restore performance. In the first iteration the restored result $\tilde{u}$ is treating as the noisy image $u$ in the second iteration. As shown in Fig. 2, the edge-based bilateral filter is composed of two phases based on the edge detector and the bilateral filter, respectively. In the edge detector phase, for the first iteration, the thresholds are determined primarily by two factors, the distribution of the edge magnitude and the noise level $\sigma_n$:

$$T_1 = \beta \cdot \text{median}(\text{mag}_u(i,j)) + \sigma_n$$

The noise level is estimated from the diagonal subband wavelet coefficients. If the image has much detail, small value $\beta$ helps to conserve more edges in the restoration, and large value $\beta$ helps to smooth more noise. The suitable range for this parameter is obtained $\beta = [0.5, 2]$ from the experimental results. In this paper, it is set $\beta = 1$ and let $T_2 = 0.4T_1$ as Canny edge detector. In the second iteration, the thresholds are the same with the first iteration. In the bilateral filter phase, there are two differences between the non-local and the local bilateral filters, one is the selecting methods for the neighbor candidates which can be seen, and other is the parameters affected the performances of the filters. The size of the window $\Omega^{N^E}_{ij}$ in the local non-edge bilateral filter is determined primarily by the noise level and the requirements on the edge. For simplicity, $N^E = 3$ and $N^N = 2$ are selected in the first and the second iteration, respectively. The nonlocal edge bilateral filter is needed a large area $\Omega^{N^E}_{ij}$: to search self-similarity by using a small block

$$\left\{ \begin{array}{l} N^E = N^N \\ N^E = 3N^N \end{array} \right. $$

And the edge region, by choosing small $\sigma_p$ and large $\sigma_D$, the edge stopping function $h_p$ has greater impact than the low-pass function $h_D$:

$$\left\{ \begin{array}{l} \sigma_D = 2N^E \\ \sigma_p = T_1 \end{array} \right.$$
On the contrary, in the non-edge region, smoothing the noise is first to be considered, so we choose small $\sigma_D$ and large $\sigma_P$:

$$
\begin{align*}
\sigma_D &= 2N^N \\
\sigma_P &= 3T_1
\end{align*}
$$

4. EXPERIMENTAL RESULTS

In this section, the proposed edge-based bilateral filter (EBF) is evaluated and compared with other existing techniques. We compare the EBF algorithm with that of non-local means (NL means) algorithm [12] and multi-resolution bilateral filter (MBF) [10] in restoring real color noisy images. The noisy image in Fig. 5(a) and Fig. 2(a) were captured with two different types of digital camera at ISO 1250 and ISO 1600 respectively, Fig. 5(a) and Fig. 3(a) were downloaded from [16]. In our color denoising algorithm, we use the edge-based bilateral filter in luminance-chrominance (YUV) color space. There are two important criteria that are widely used to judge the visual quality of restoration of real noisy image: the conservation of image features and the reduction of noise level. As we know, it is hard to balance both of them. In Figs. 3 and Figs. 4, the NL-means conserves most of image features, but it also leaves some noise. On the contrary, in order to remove noise, the MBF loses some image features and color. By contrast, the EBF removes most noise and preserves image features with high performance, because it adopts different strategies in the edge and the non-edge region.

5. CONCLUSION

In this paper, an efficient bilateral filter is proposed for restoring real noisy images, in which the strategies and parameters are directly based on the edge detection results. Extensive experimental results are shown that the new method is competitive with other denoising techniques.

REFERENCES


