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An Edge Preserving Filter-based Selective Unsharp Masking for Noisy Images

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Abstract: In this paper, a new image sharpening method is proposed. The proposed method is a kind of selective unsharp masking, and it has an advantage on enhancement of the noisy images. And, the optimum values of parameters of the proposed method can be determined by the amplitude of an additive noise. The effectiveness of the proposed method is illustrated through the comparison with the conventional unsharp masking and cubic unsharp masking.

1. Introduction

Unsharp masking (UM) has been used widely in order to sharpen the blurred image. In UM, edges of an image are mainly enhanced, and then a sharpened image is obtained [1]. However, in case where the image is corrupted by an additive noise, there is a drawback that is to enhance not only the original signal but also the noise. A noise enhanced image gives the uncomfortable impression to observers.

To cope with the problem that noises are also enhanced when UM is applied to noisy images, G. Ramponi proposed cubic unsharp masking (CUM) which has robustness against additive noises [2]. CUM is a kind of selective unsharp masking methods. In CUM, the coefficient to adjust the enhancement effect is determined for each pixel by using the local information of an input image.

To suppress the noise enhancement in the plane region of an input image, in CUM, the coefficient of the enhancement is decided by the edge information of an input image. And the edge information is calculated by based on the brightness gradient for each pixel. When the gradient value is large, the pixel of concern is regarded as a part of an edge, and the coefficient of the enhancement is set as a large value. Contrastively, when the gradient value is small, the pixel of concern is regarded as a part of a plane region, and the effect of enhancement is suppressed by assigning a small value to the coefficient.

In UM, a deterioration of image quality caused by the noise enhancement is remarkable especially in the plane region of an image. So, the resulting image obtained by CUM is relatively good in comparison with the result of the conventional UM. However, noises can not be removed at all in the CUM. Moreover, noises are also enhanced slightly in the plane region.

In this paper, a new image sharpening method, which is robust for the additive noise, is proposed. The proposed method is designed based on the edge-preserving noise removal and the selective image sharpening techniques. The effectiveness of the proposed method is verified through the experiments.

2. Proposed Selective Unsharp Masking

The proposed method is realized by using the edge-preserving noise removal and the image sharpening techniques. In this section, these techniques used here, that is, ε-filter and UM are described at first. Then, details of the proposed method are given.

2.1 ε-filter

A number of noise removal filters have been proposed. In this study, ε-filter proposed by Harashima et al. [3] is employed to remove the noises of an input image. ε-filter is one of edge-preserving smoothing filters and it is quite useful to remove the small amplitude noises.

An output image I_ε processed by ε-filter is given by:

$$I_\varepsilon(x,y) = I(x,y) - \sum_{i=-r}^{r}\sum_{j=-r}^{r}\big[\,a(i,j) \times F(I(x,y) - I(x+i,y+j))\big], \quad (1)$$

where r is a size of the processing window in the filtering, and is a positive integer number. F is the function which is satisfied the following relationship:

$$|F(z)| \leq \varepsilon \quad (2)$$

in $-\infty < z < \infty$. The function F used in this study is defined as follows:

$$F(z) = \begin{cases} \varepsilon & z > \varepsilon \\ z & -\varepsilon \leq z \leq \varepsilon \\ -\varepsilon & \text{otherwise.} \end{cases} \quad (3)$$

In Eq.(1), a stands for a weight for filtering. Here, the values of a's are defined as follows:

$$a(i,j) = \kappa \exp\left(-\frac{i^2+j^2}{2\sigma_\varepsilon^2}\right), \quad (4)$$

where κ is the constant for the normalization, and it is defined to be satisfied the following condition:

$$\sum_{i=-r}^{r}\sum_{j=-r}^{r} a(i,j) = 1. \quad (5)$$

In Eq.(4), σ_ε is the standard deviation of the Gaussian function. And, the value of r is even enough in the case it set to $3\sigma_\varepsilon$.

2.2 Unsharp Masking

UM is a method to enhance high frequency components of an image. It mainly enhances edge parts of an input image, and the resulting edge enhanced image gives sharpened impression to observers.

In UM, the high frequency components of the input image are extracted, and the image sharpening is achieved by adding the high frequency components into the input image. The sharpened image I' obtained by UM is defined as follows:

$$I'(x, y) = I(x, y) + \lambda H(x, y), \tag{6}$$

where $I(x, y)$ means a pixel value of an input image at (x, y), and λ is a parameter deciding the strength of enhancement. λ should be set as a positive real value. H stands for the output of the high-pass filtering of an input image. In many cases, 4-neighbors Laplacian filter is employed as the high-pass filter in UM. 4-neighbors Laplacian filter used here is defined as follows:

$$\begin{aligned} H(x, y) &= -\nabla^2 I(x, y) \\ &= 4I(x, y) - I(x-1, y) - I(x+1, y) \\ &\quad - I(x, y-1) - I(x, y+1). \end{aligned} \tag{7}$$

2.3 Algorithm of the Proposed Method

In the proposed method, ε-image, which is a noise removed image processed by ε-filter, is firstly obtained. Then, UM process is applied to ε-image. Finally, the output image is obtained by a weighted sum of ε-image and its enhanced image by UM. The weight for each pixel is decided by the local statistics of the input image and ε-image. Therefore, the proposed method is regarded as a kind of selective UM to ε-image. Figure 1 shows the schematic diagram of the proposed method. The concrete procedures of the proposed method are described below.

An output image $\tilde{I}$ of the proposed method is obtained as follows:

$$\tilde{I}(x, y) = w(x, y) I'_\varepsilon(x, y) + (1-w(x, y))\, I_\varepsilon(x, y), \tag{8}$$

where I_ε is the ε-image, and I'_ε is the sharpened image of I_ε by UM. $w(x, y)$ is a weight for the pixel (x, y), and is defined as:

$$w(x, y) = \begin{cases} 0 & v(x, y) = 0 \\ \Phi(v_\varepsilon(x, y)/v(x, y)) & \text{otherwise,} \end{cases} \tag{9}$$

and

$$\Phi(x) = \begin{cases} x & x < 1 \\ 1 & \text{otherwise.} \end{cases} \tag{10}$$

In Eq.(9), $v(x, y)$ stands for a local variance of pixel values of an input image. The local region surrounding $I(x, y)$ of size $\rho \times \rho$ (ρ is a positive odd integer, and is larger than or equal to 3) is considered, and the variance of pixel values in the region

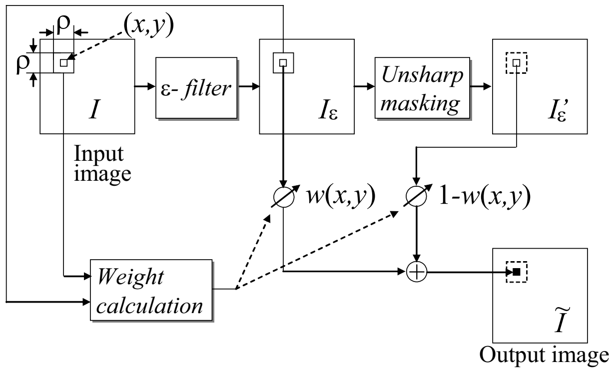

Figure 1. A schematic diagram of the proposed method.

is calculated. $v_\varepsilon(x, y)$ is the local variance of $I_\varepsilon(x, y)$, and is calculated in the similar manner to $v(x, y)$.

The local variance is related to whether the edge is included in the local region or not. In case where the local region includes the edges, v and v_ε tend to be large values. Therefore, the ratio v_ε/v becomes near to 1. Contrastively, v_ε tend to be nearly 0 when the local region includes only plane region, and the ratio v_ε/v becomes near to 0 in that occasion. The pixels located near to or on the edges should be enhanced in image sharpening. On the other hand, the plane region should not be enhanced and to be smoothed. Eq.(8) executes the switched processing mentioned above without parameters. And, function Φ has a role of normalization. The range of w becomes $[0, 1]$ after a calculation of Φ.

By the way, by using Eqs.(6) and (7), Eq.(8) can be rewritten as follows:

$$\begin{aligned} I'(x, y) &= w(x, y) \left(I_\varepsilon(x, y) - \lambda \nabla^2 I_\varepsilon(x, y) \right) \\ &\quad + (1 - w(x, y)) I_\varepsilon(x, y) \\ &= I_\varepsilon(x, y) - \lambda w(x, y) \nabla^2 I_\varepsilon(x, y) \\ &= I_\varepsilon(x, y) - \lambda'(x, y) \nabla^2 I_\varepsilon(x, y). \end{aligned} \tag{11}$$

Here, $\lambda'(x, y)$ means $\lambda w(x, y)$. From Eq.(11), it can be said that the proposed method is a kind of selective UM to I_ε.

3. Determination of Parameters

The proposed method has four parameters ε, σ_ε, λ, and ρ. ε and σ_ε are parameters concerning the ε-filter, λ is the coefficient of enhancement, and ρ is the local region size for calculating the weight.

λ should be tuned so that the sharpness of a resulting image becomes suitable for a user's demand. The values of other three parameters can be determined by some experiments using the indices of image quality. In this paper, as the indices of image quality, the Detail variance and Background variance (DV-BV) proposed by G. Ramponi [2] are employed. DV is related to the sharpness of an image and BV is related to the noise intensity.

Though ε-filter is an edge-preserving smoothing filter, it can not avoid edge destruction due to smoothing. It can be said that an ideal edge-preserving smoothing keeps DV value

Table 1. DV's and BV's of images obtained by various methods.

Input image	$\sigma_N = 5$, $(\mathrm{DV}, \mathrm{BV}) = (992, 59.9)$				$\sigma_N = 10$, $(\mathrm{DV}, \mathrm{BV}) = (947, 116)$				$\sigma_N = 15$, $(\mathrm{DV}, \mathrm{BV}) = (745, 178)$			
Objective DV	1500		2000		1400		1900		1100		1500	
	DV	BV	DV	BV	DV	BV	DV	BV	DV	BV	DV	BV
UM	1492	112	2005	176	1403	233	1902	383	1093	316	1515	500
S-CUM	1499	63.0	2003	70.7	1405	124	1899	143	1099	202	1500	251
Proposed method	1496	45.2	2002	58.9	1400	37.9	1907	51.3	1095	43.5	1495	89.1

Figure 2. The test image Lenna included in SIDBA.

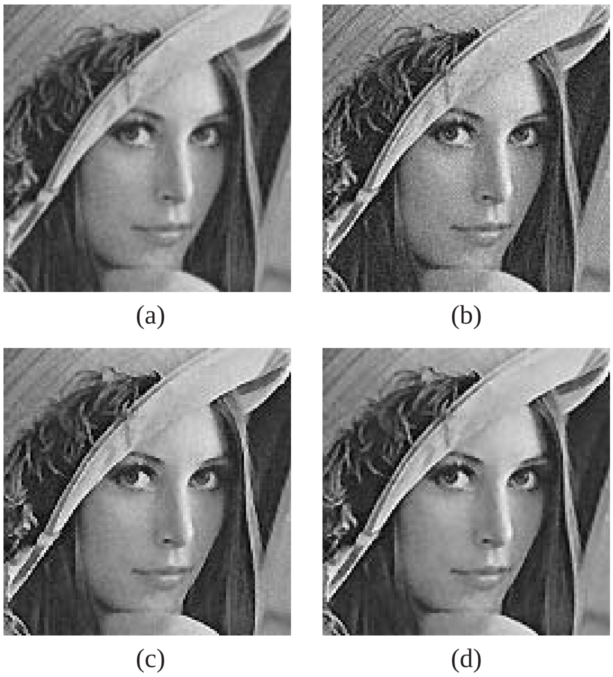

Figure 3. Resulting images obtained in case where objective DV is set to 2000. (a) Input image (Lenna, $\sigma_N = 5$), (b) UM, (c) CUM, (d) Proposed method.

of the image as it is while BV value is reduced after processing. The values of ε and σ_ε (parameters of ε-filter) are adjusted experimentally using the DV-BV.

In our experiments, the ratio value DV/BV is defined as the accuracy index of edge-preserving smoothing. Because an ideal edge-preserving noise removal reduces BV value while keeps DV value as it is. The values of parameters yielding large DV/BV are good for edge-preserving noise removal. Through the experiments, we could obtain the relationship between the good ε and the noise amplitude of an input image. That can be written as:

$$\varepsilon = 2\sigma_N + 10. \tag{12}$$

Here, σ_N stands for a standard deviation of the additive Gaussian noises. If σ_N is acquired by a certain method, the optimum ε is determined by using Eq.(12).

Similar to ε, the relationship between the good σ_ε and σ_N was obtained through the experiments that examined the noise removal ability of the proposed method. The obtained relationship is given by:

$$\sigma_\varepsilon = 0.04\sigma_N + 0.4. \tag{13}$$

And, the parameter ρ (local region size) is also adjusted based on DV-BV. An ideal noise robust image sharpening increases DV value of image while BV keeps small value. However, after the experiments, it is revealed that the effect of changing a value of ρ is not so significant. Therefore, $\rho = 3$, which is the parameter of the least calculation cost, is employed.

4. Experimental Results

The effectiveness of the proposed method is verified by comparing with the conventional UM and CUM. In this paper, the ability of the noise robustness is measured by DV-BV. At first, the objective DV is set in our experiment. And the coefficients of enhancement of each method are tuned so that DV value of resulting image becomes close to the objective DV. Then, the method which produces the smaller BV result is judged as the excellent method. The parameters of the proposed method, ε, σ_ε, and ρ, are set to optimum values previously obtained.

The standard image Lenna included in SIDBA [4] was employed in the experiments, and the original Lenna is shown in Fig.2. Images of Lenna corrupted by additive Gaussian noises, whose standard deviations were $\sigma_N = 5$, $\sigma_N = 10$, and $\sigma_N = 15$, were employed in experiments. And, objective DV's are set to 1.5 or 2.0 times larger that of the input images.

Table 1 shows DV-BV's of the images obtained by UM, CUM, and the proposed method. The values shown in Table 1 reveal that the proposed method always produces the smallest BV result. From an evaluation of DV-BV, it can be said that the proposed method is superior to CM and CUM.

Moreover, resulting images obtained by the proposed method are also visually good in case where the standard deviation of the noise is relatively small. However, when the

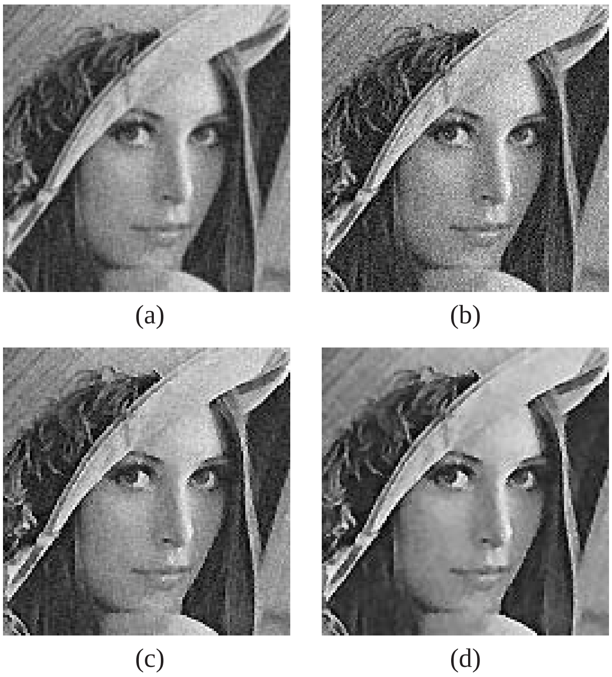

Figure 4. Resulting images obtained in case where objective DV is set to 1900. (a) Input image (Lenna, $\sigma_N = 10$), (b) UM, (c) CUM, (d) Proposed method.

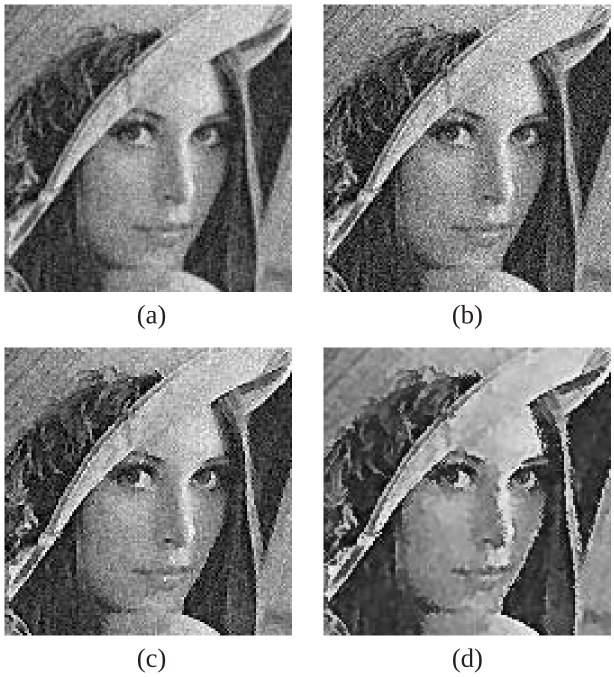

Figure 5. Resulting images obtained in case where objective DV is set to 1400. (a) Input image (Lenna, $\sigma_N = 15$), (b) UM, (c) CUM, (d) Proposed method.

standard deviation of the noise is large, the results obtained by the proposed method is visually poor nevertheless BV value of it is small. The examples of resulting images obtained by various methods and in various conditions are shown in Figs.3, 4, and 5. Figure 3 shows the results obtained in case $\sigma_N = 5$. Similarly, Figs.4 and 5 show the results obtained in case $\sigma_N = 10$ and $\sigma_N = 15$, respectively. In Figs.3, 4 and 5, (a), (b), (c), and (d) show input image, the result obtained by UM, the result obtained by CUM, the result obtained by the proposed method, respectively. All images shown in Figs.3, 4, and 5 are partial and magnified ones to ease the observation.

In Fig.3, the resulting images obtained by CUM and the proposed method are visually good (Figs.3(c) and (d)). The noise robustness of these methods are confirmed in comparison with the resulting image obtained by UM shown in Fig.3(b).

Then, the obvious effectiveness of the proposed method is observed in Fig.4. UM enhances the noises strongly as shown in Fig.4(b). The resulting image obtained by CUM (Fig.4(c)) is relatively good in comparison with that of UM. It is observed that the noise enhancement is saved. However, it can be said that the result obtained by the proposed method shown in Fig.4(d) is superior to other results. The balance of noise removal and image enhancement is good and the impression of the output image is excellent.

Finally, Fig.5 shows the results in case where the standard deviation of the noise is large. From Fig.5, it is observed that UM, CUM, and the proposed method could not enhance the image well. UM and CUM enhances noises and edges simultaneously as shown in Figs.5(b) and (c). In the proposed method, noise enhancement is relatively saved, however deterioration of the outlines of the objects are observed as shown in Fig.5(d).

From Figs.3, 4, and 5, it is confirmed that the proposed method has an obvious advantage in case σ_N is about 10. And, in case where the standard deviation of the noise is smaller than 10, the proposed method also works well.

5. Conclusions

In this paper, we proposed a new selective unsharp masking method, which is based on ε-filter and the conventional UM, for noisy images. From the experimental results, it is confirmed that the proposed method is effective for the image corrupted by small amplitude noises.

A future work is to improve the proposed method as it can be applicable to large amplitude noises.

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