A ROBUST ADAPTIVE IMAGE SMOOTHING ALGORITHM

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ABSTRACT:

Image smoothing is a key technology of image enhancement, which can remove noise in images. So, it is a necessary functional module in various image-processing software. Excellent smoothing algorithm can both remove various noises and preserve details. This paper analyzed some image smoothing algorithms. These algorithms have the ability of preserving details, such as gradient weighting filtering, self-adaptive median filtering, robust smoothing and edge preserving filtering. A robust smoothing algorithm is presented by combining non-linear and linear filtering according to the respective adaptation to different noises. Tests on images corrupted with various noises show that the new algorithm can both deal with corrupted images robustly and preserve details well.

1. INTRODUCTION

The main aim of image smoothing is to remove noise in digital images. It is a classical matter in digital image processing to smooth image. And it has been widely used in many fields, such as image display, image transmission and image analysis, etc. Image smoothing has been a basic module in almost all the image processing software. So, it is worth studying more deeply.

Image smoothing is a method of improving the quality of images. Its main purpose is to be fit for the man's physiological vision system. The objects processed are images corrupted with different factors during the course of their generation, transmission, process and display, etc. In the whole Image Processing system, image smoothing is a special technology of image recovery. It is fit for smoothing images in which the degradation is only caused by noise. Because image smoothing is a classical matter, a lot of algorithms come into practice based on the practical requirement and the development of related technology. The algorithms include mean filtering, Gauss filtering, gradient weighting filtering, sequence statistical filtering, robust smoothing filtering, Crimmins noise remove filtering, edge preserved filtering and self-adaptive median filtering, etc [1][2][3].

There are many factors that can cause the existence of noise. Different factors can cause different kinds of noise. In practice, an image usually contains some different types of noise. So good image smoothing algorithm should be able to deal with different types of noise. However, image smoothing often causes blur and offsets of the edges. While the edge information is much important for image analysis and interpretation. So, it should be considered to keep the precision of edge's position in image smoothing. In this paper, some image smoothing algorithms (gradient weighting filtering, self-adaptive median filtering, robust smoothing filtering, edge preserved filtering) whose capability of preserving details is better are analysed. Then, a new algorithm of image smoothing is presented by combining non－linear filtering and linear filtering according to their respective adaptation to different noise. In order to prove the smoothing effect, we adopt the image blur degree based on fuzzy math to evaluate the quality of the smoothed images. The experimental results show that the new algorithm can both remove different noises and preserve the details more effectively in image.

2. THE ANALYSIS OF SOME SMOOTHING ALGORITHMS[1]~[5]

By analyzing these algorithms, we find some merits and demerits of them in preserving image details. Having inherited these merits, we propose a new algorithm which is more robust, more adaptive and better at smoothing images.

2.1 Edge Preserved filtering

Typical edge preserved filtering includes two types: Kuwahara filtering and selective mask filtering. The basic process of them is described as follows: Firstly, some different templates are made based on the center pixel. Secondly, the mean value and the standard deviation of the pixels in different templates are calculated. Finally, the gray value of the center pixel is defined as the mean value in the template where the standard deviation is the least. The Kuwahara filtering selects one template from 4 square windows. While the selective mask filtering chooses one template region from 9 windows, which include 4 pentagon, 4 hexagon and 1 square .The effect of preserving details of the selective mask filtering is better than that of the Kuwahara filtering, because the former has more fine window choice.

Through the analysis of these algorithms, we find that the image details can be preserved from selecting a suitable template according to the rule of minimizing the standard deviation. When the template is selected, we can use other smoothing algorithms with better smoothing effects. For example, considering that the medium filtering can preserve details more effectively than mean filter does and that it is more effective for salt and pepper noise, we can take the medium grey value in the template window where the standard deviation is the least as the grey value on the centre pixel. And so we can remove salt and pepper noise more effectively.

2.2 Adaptive medium filter

This algorithm is a betterment filtering to the medium one. Comparing with medium filter, it can deal with pulse noise in higher density. What's more, it can preserve more image details when dealing with non-pulse noises. We define the symbols as follows: Sx,y is the template window of the center pixel(x,y), Zmin is the minimum grey in window Sx,y, Zmax is the maximum grey in Sx,y, Zmed is the medium grey in Sx,y, Zx,y is the grey value in pixel(x,y), Smax is the tolerable maximum scale of Sx,y. The adaptive medium filtering works in two steps:

Step A :

A1= Zmed－ Zmin，A2= Zmax－ Zmed.

If A1>0 and A2>0，go to step B.

Else, enlarge the window.

If window ≤Smax, repeat step A.

Else, output Zx,y.

Step B:

B1= Zx,y－ Zmin，B2= Zmax －Zx,y.

If B1>0 and B2>0, Zx,y is output.

Else, Zmed is output.

Step A is used to judge whether Zmed is a pulse. Step B is used to decide whether Zx,y is a pulse. If Zmed and Zx,y are both not pulse, then a constant value Zx,y is output to replace the medium value to avoid unnecessary losing of other detail information. In order to resolve the matter of the standard medium filtering on dealing with higher density pulse, the strategy of enlarging windows is adopted in the adaptive medium filtering to reduce the space density of pulse noises. As an improvement of the strategy, it can adopt the idea of the selecting templates, that is, reducing the space density of the pulse noises by change the shape and orientation of the window. An advantage of this method is that it can preserve more details by changing window's shape and orientation in two parts of neighborhood and by avoiding the situation of one window including pixels in two different parts caused by enlarging window's size.

2.3 Robust smoothing filter

Robust smoothing filter is a simple and fast non－linear filter. It can remove salt and pepper noise with lower density effectively. Because it adopts the strategy of losing the ability of smoothing to preserve edges, it can preserve more edge details than the medium filtering can do. The process can be described as follows:

（1）Calculate the maximum and the minimum of the gray values in the template window except the centre pixel.

（2）Compare the gray value on the centre pixel with the maximum and the minimum.

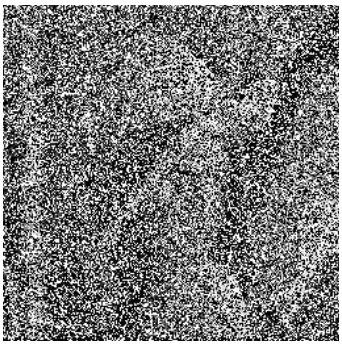
（3）If the gray value is larger than the maximum , the maximum is output; If the gray value is smaller than the minimum, the minimum is output; If the gray value is between them, the gray value is output.

In order to preserve more details, we adopt the same idea in robust smoothing filtering as in the adaptive medium filtering. It can reduce the image distortion by unchanging the gray on 'middle level' pixels. However, the robust smoothing filtering only can remove salt and pepper noise with lower density. In order to overcome this weakness, an improved algorithm is presented as follows:

（1）Select the pixels where the gray is not equal to that on the centre pixel in the template window, and sort the gray values on the selected pixels to get the medium one.

（2）Compare the gray value on the centre pixel with the maximum and the minimum. If the gray is between them, it is output. If it is larger than the maximum, the medium gray is compared with the maximum and the minimum. If the medium gray is between them, it is output. Else the maximum is output. Likely, if the value on centre pixel is smaller than the minimum, and the medium gray is between the maximum and the minimum, the medium value is output. Otherwise, the minimum is output.

The amended robust smoothing algorithm can both deal with 'salt and pepper' noise with thick density and restrain the Gauss noise in some extent. Compared with the adaptive medium filtering, it has the advantage of less calculation to get the same smoothing effect. Figure 1 shows the smoothing results of the image added salt and pepper noise with space density 0.7：



（a）The image corrupted with salt and pepper noise

(b) The result smoothed by robust smoothing method

(c)The result smoothed by the amended method

Fig.1 The results smoothed by the robust smoothing filtering and the amended one

2.4 Gradient weighting filter

The gradient-dependent weighting filters are mainly based on the following principle: in a discrete image, the difference of the gray values on pixels in outer area is larger than that in inner area. In same area, the change on centre pixels is smaller than that on edge pixels. The gray gradient is direct ratio to the gray difference in vicinity. That is, where the gray change is slower, the gradient is smaller. A function whose value reduces with the increase of the gradient is adopted, and it is chosen as the weight of the window. So, the smoothing contribution is mainly coming from the same area. Accordingly the edge and the detail cannot be lost apparently after image smoothing.

In designing gradient-selected filters, power and exponential function are often chosen as weighting function. Especially when the power is equal to –1, the filtering is called gradient reciprocal weighting filtering. When the function is the exponential one, the filtering is called adaptive filtering. When we extract lines from remote sensing images, the adaptive filtering is often adopted in pre－processing to realize the aim of noise removal and edge enhancement. It can be described as:

$$f(x) = e^{-x^2/2k^2} .$$

Where, x is the gradient, k is the parameter that determines the smoothing degree.

By analysis, we find that k can be used to adjust the degree of sharp of the exponential function. If k is bigger, the exponential function will be slower in change. So, if the gradient is bigger than k, the gradient will increase with the adding of the iterative times, so as to realize the aim of sharping edge. Oppositely, if the gradient is smaller than k, the details will be smoothed. Thus, the value of k is critical to the smoothing effect. But, there are not so many quantitative analysis of k in the description of adaptive filter. Considering the above factor, this paper discusses the selection of k and its influence to the gradient weighting filtering, which can be described as follows:

① Modify the gradient intensity image. That is, adding a negative value to the gradient intensity on each pixel, so as the mean gradient intensity is equal to zero.

② Calculate the square errors of the new image: $\sigma^2=E(x-Ex)^2=Ex^2$. Where, Ex is the mean gray gradient, x is the gradient intensity on the corresponding pixel.

③ Assume $k=\sigma$, the exponential function will be the standard normal distribution. Adopting this value as the parameter, we can remove noise and preserve detail simultaneously.

3. ROBUST ADAPTIVE SMOOTHING ALGORITHM

The robust adaptive smoothing algorithm absorbs the merits of the above methods. It synthetically combines the following ideas: multi-window templates, gradient weighting, constant gray output on non-pulse pixel and the amended adaptive smoothing algorithm. If the symbols are the same as that in the medium filtering, the processing steps can be described as follows：

（1） According to the selecting template filtering algorithm, select 9 sub template windows, which include 4 pentagon, 4 hexagon and 1 square in window $S_{x,y}$. The orientation and shape of the sub template windows are shown in Figure 2.

（2） In the 9 sub template windows, if a window satisfies the following conditions: $A1= Z_{med}-Z_{min}>0$，$A2= Z_{max}-Z_{med}>0$，$B1= Z_{x,y}-Z_{min}>0$，$B2= Z_{max}-Z_{x,y}>0$，$Z_{x,y}$ is output. Else，go to step 3.

（3） In each sub template window where A1>0 and A2>0, the output Z grad is calculated according to the gradient weighting filtering algorithm(this paper adopts the adaptive filtering). If the difference between Z grad and Zmed is smaller than the threshold, the mean of Z grad and Zmed is output. Else, the window is enlarged.

（4） If the window is enlarged to scale Smax and there is none satisfied output, $Z_{x,y}$ is preserved to next cycle.

（5） The above 4 steps are performed until getting satisfied smoothing effect.

In order to preserve more details, this paper adopts the method that preserves gray value on pixel where there is not shot noise. Simultaneously, this paper adopts the methods of enlarging windows and selecting sub template windows to remove salt and pepper noise with large space intensity. Because it both uses linear filtering and non－linear filtering, this algorithm has better flexibility for many types of noise.

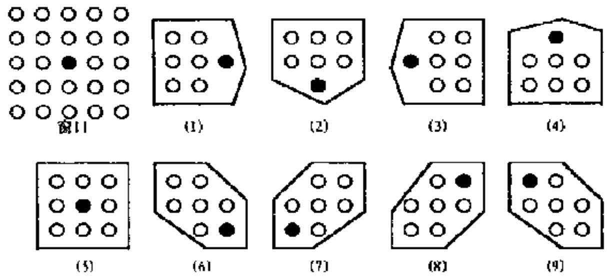


Fig. 2 5×5Window and its 9 sub template windows，● presents the centre pixel

4. THE EVALUATION OF SMOOTHING EFFECT

The algorithm proposed in this paper and some other algorithms are compared and analysed to evaluate the effects of smoothing, according to the criterion of image fuzzy degree. The smoothing abilities of them are tested through extracting the edges both from the original images and the smoothed ones.

4.1 Smoothing quality comparisons of the algorithms

This paper adopts the image blur degree based on fuzzy math [6] presented by Xu Yan and Wang Chao to evaluate the smoothing effects of the filtering methods reasonably. The criterion can show both the clear level of the edges and the blur degree of the whole image, whose algorithm can be seen in Reference [6]. Figure 3 shows the Lena image added ‘salt and pepper’ noise in intensity of 0.3 and the images smoothed with the following three algorithms: the algorithm presented in this paper, the algorithm of the amended smoothing filtering and the one of the adaptive medium filtering.

(a) The Lena image with noise (intensity 0.3)

(b) The result by the amended robust smoothing filter（blur degree 0.28）

(c) The result smoothed by the adapted medium filter (blur degree 0.29)

(d) The result smoothed by the presented algorithm

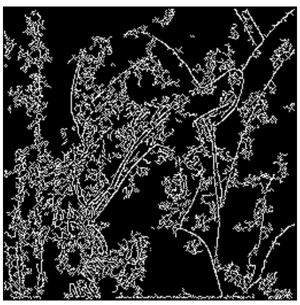
Fig. 3 The results smoothed by different algorithms

From figure 3, we can see that the algorithm presented in this paper can preserve edge more effectively.

4.2 The analysis of smoothing ability

Figure 4(a) shows the Lena image with noise whose intensity is 0.01. The edge extraction results from the original image and from the smoothed one using the method presented

(a) The Lena image with Gaussian noise of 0.01intensity



(b) The edge extraction result before smoothing

in the paper is shown in figure 4(b)、(c). From the results, we can find that this algorithm can remove Gaussian noise effectively.

5. CONCLUSION

This paper analysed some smoothing algorithms whose abilities of preserve detail are better. These algorithms include adaptive medium filtering, gradient weighting filtering, robust smoothing filtering and edge preserved filtering. This paper

(c) The edge extraction result after smoothing

Fig. 4 The edge extraction results of Lena images

presents a new algorithm by combining non－linear filtering and linear filtering according to their respective adaptation to different noises. Experimental results show that the algorithm works well on both denoiseing images and preserving details.

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