A gray-natural logarithm ratio bilateral filtering method for image processing

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A new method based on gray-natural logarithm ratio bilateral filtering is presented for image smoothing in this work. A new gray-natural logarithm ratio range filter kernel, leading to adaptive magnitude from image gray distinction information, is pointed out for the bilateral filtering. The new method can not only well restrain noise but also keep much more weak edges and details of an image, and preserve the original color transition of color images. Experimental results show the effectiveness for image denoising with our method.

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Imaging is one of the most important approaches to capturing information. However, image degrades and may be affected by the noises during imaging, transmission, compression, and other processing. The noise should be eliminated by image smoothing. In the past decade, the representative research achievements were obtained at edge preserving smoothing based on nonlinear image filtering method[1−6], including minimizer of energy functional method[1], regularization method[2], anisotropic diffusion method[3], and nonlinear digital filter method[4]. Bilateral filtering[7] was proposed by Tomasi and Manduchi in recent years. The kernel of bilateral filter was composed of an inner product of two filters in real space: a domain filter and a range filter. Bilateral filter is a nonlinear, non-iterative, and non-local filter and is the most representative nonlinear digital filter of applicable value.

In recent years, the researches based on bilateral filtering mainly feature the relationships between the bilateral filtering, partial differential equation (PDE), neighborhood filtering[8,9], fast algorithm for bilateral filtering[10], and bilateral mesh denoising[11]. However, the researches in improving edge-preserved detail maintenance has been just brought into attention recently[12]. In this work, we will analyze the original bilateral filtering, modify the original model to keep much more edge details of an image, and preserve the original color transition of color images.

The central idea in the design of any image-smoothing filter is that pixels in close geometric proximity have similar contents. Thus, it is assumed safe to average over close pixels. However, this central idea breaks down at the ‘edges’ of an image. In this context, ‘edges’ refer to those points on an image where there are discontinuities or sharp contrasts between a pixel’s content and its immediate neighbor’s. The bilateral filter accounts for the edges by weighting pixels based on their photometric similarity in addition to geometric proximity. Therefore, the bilateral filter kernel is a composite kernel consisting of a domain filter kernel and a range filter kernel. The domain filter kernel weights pixel contents based on geometric proximity to the center pixel, while the range filter kernel weights the pixel contents based on photometric similarity to the center pixel. These ideas are expressed mathematically as

$$J(x)=\frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}f(\xi)c(\xi,x)h(f(\xi),f(x))\mathrm{d}\xi}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}c(\xi,x)h(f(\xi),f(x))\mathrm{d}\xi},\tag{1}$$

where $J(x)$ is the estimator of the current pixel x, $f(x)$ is the pixel value of x, $f(\xi)$ is the pixel value of its neighbor(s) ξ, $h(f(\xi),f(x))$ is the range filter kernel, and $c(\xi,x)$ is the domain filter kernel.

The Gaussian function is a natural candidate for implementing a weighting scheme. It has most of its weight at or near the center and exponentially diminishes away from the center. Thus, both the domain filter kernel $c(\xi,x)$ and the range filter kernel $h(f(\xi),f(x))$ have been designed with the Gaussian function as

$$c(\xi,x)=\mathrm{e}^{-(\|\xi-x\|)^2/2\sigma_c^2},\tag{2}$$

$$h(f(\xi),f(x))=\mathrm{e}^{-(\|f(\xi)-f(x)\|)^2/2\sigma_h^2},\tag{3}$$

where $\|\cdot\|$ is the Euclidean distance in Gaussian function, σ_c and σ_h are the standard deviations for domain filter and range filter functions.

Bilateral filtering makes the tradeoff between photometric similarity and geometric proximity. The pixel intensity value differences represented by the weak edges are always covered up by photometric similarity and geometric proximity when they are processed by bilateral filters in the same scale. The results are that the strong edges are preserved, the weak edges are smoothed, and the color transition tends to become mild when smoothing is done with color image. In order to preserve the most of weak edges and color transition, we keep the domain filter kernel and replace the original range filter kernel with a new gray-natural logarithm ratio range filter kernel, for which the Euclidean distance $\|f(\xi)-f(x)\|$ in Gaussian function is replaced with gray-natural logarithm ratio item $\ln(f(\xi)/f(x))$. The modified range filter kernel reads

$$g(f(\xi),f(x)) = \mathrm{e}^{-(\ln(f(\xi)/f(x)))^2/2\sigma_c^2}/(f(\xi)/f(x)). \quad (4)$$

Computed with the gray-natural logarithm ratio item, the variation rates of different gray sections, which have the same gray Euclidean distance, are different. The figures of gray-natural logarithm ratio item demonstrate that the variation rate is small when the gray Euclidean distance is big, but the variation rate is big when gray Euclidean distance is small, and there is a much more evident effect on the variation rate when the gray Euclidean distance is closest to zero. However, with the original range filter, the variation rate is zero whatever the gray Euclidean distance and gray sections are. The denominator item is used to accelerate the speed of variation. The variation rate is accelerated more obviously for small gray Euclidean distance than big gray Euclidean distance.

Considering a sharp boundary between a dark and a bright regions, such as strong edge in an image, processed by the original bilateral filtering, which makes the tradeoff between geometric proximity and photometric similarity that has the same gray distinction in a certain range. The dark or bright pixel is replaced by an average of the dark or bright pixels in its vicinity. The filtering behavior is achieved at the strong edge with big gray distinction, but the weak edges or some details with small gray distinction are smoothed, and the color transition of color images tends to become mild.

Considering now a weak edge or some details with small gray distinction, the pixels of different gray levels describe different characters by using the new range filter kernel. The characters are quite different in the regions with small gray distinction and small gray level. Therefore, after making the tradeoff between photometric similarity and geometric proximity, the dark or bright pixel is replaced by an average of the dark or bright pixels in its vicinity with approximate gray-natural logarithm ratio item and gray level. We preserve the weak edge and some details with small gray distinction and small gray level, and then the original color transition of color images. At the strong edge with big gray distinction or in smooth regions, the new photometric similarity function works as effectively as the original bilateral filtering.

The process is approximated by the following discrete scheme:

$$J(x) = \sum_{\xi\in\Omega} I_\xi c(\xi,x)g(f(\xi),f(x))/\sum_{\xi\in\Omega} c(\xi,x)g(f(\xi),f(x)). \quad (5)$$

In order to validate the scheme, we choose black-and-white image and color image with different standard deviations of the Gaussian noise and compare the denosing results of the original filtering model with our filtering model.

In the black-and-white image (Fig. 1(a)), we added 10 standard deviations of the Gaussian noise, and smoothed the noisy image (Fig. 1(b)) with two methods. The following parameters were adopted: bilateral filter half-

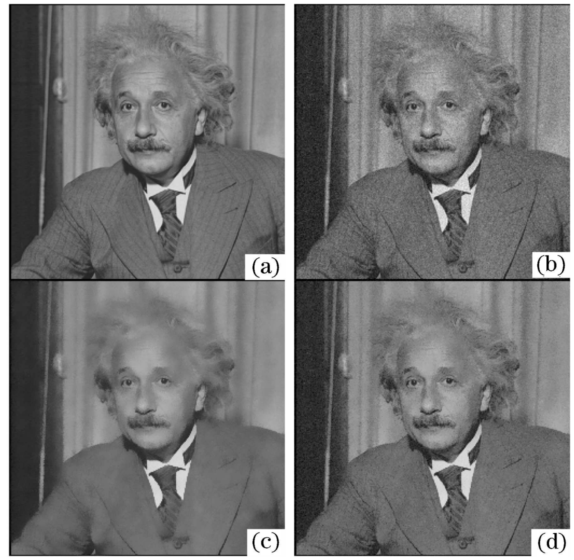

Fig. 1. Filtering a black-and-white image. (a) Original image; (b) noisy image; (c) filtered with original bilateral filtering; (d) filtered with our method.

Table 1. PSNR of Experimental Results for Processing a Black-and-White Image

Gaussian Noise	Noise Image	Bilateral Filtering	Our Method
$\sigma = 15$	24.6048	33.6346	32.1505
$\sigma = 20$	22.1060	31.5589	30.2383
$\sigma = 25$	20.1678	30.2895	29.2176

width $w = 5$, bilateral filter standard deviations for proximity and similarity functions $r = 3$, $d = 0.1$. Comparing the results given in Figs. 1(c) and (d), we can see that the details of the suit, hair, and mustache in Fig. 1(d) are preserved very well, while the same parts in Fig. 1(c) are blurry. Peak signal-to-noise ratio (PSNR) is an important indicator for the denoising effect. Table 1 lists the PSNR of the experimental results. It is shown that the quality of image processed by our method maintains the performance of original bilateral filtering basically.

In a color image (Fig. 2(a)), we added 15 standard deviations of the Gaussian noise, smoothed the noisy image with two methods, and adopted the following parameters: half-width $w = 5$ and standard deviations $r = 3$, $d = 0.1$. Comparing the results in Figs. 2(c) and (d), we can also find that the details of the mustache and the hair around the jowl in Fig. 2(d) are preserved great better than the same parts in Fig. 2(c). And color transition with our method is closer to original image than that with the original bilateral filtering (not shown clearly in the gray images). Experiments show that our method can not only well restrain noise but also keep much more edge details of an image, and preserve the original color transition of color images.

In conclusion, based on the analysis on the original bilateral filtering method, a new method based on gray-natural logarithm ratio bilateral filtering is presented for image smoothing. A new gray-natural logarithm ratio range filter kernel, leading to adaptive magnitude from

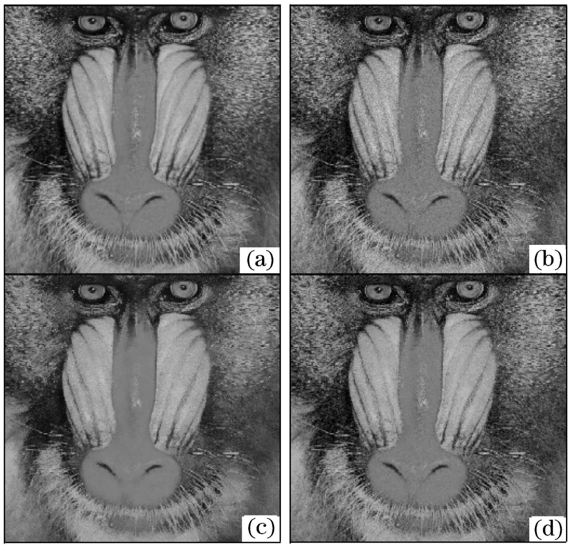

Fig. 2. Filtering a color image. (a) Original image; (b) noisy image; (c) filtered with original bilateral filtering; (d) filtered with our method.

image gray distinction information, is pointed out for the bilateral filtering. Experimental results show that the effectiveness for image denoising with our method is better than the original method.

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