Image Enhancement Using Multi-scale Gradients of the Wavelet Transform

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Abstract: In this paper, we propose new unsharp masking technique based on the multiscale gradient planes. The unsharp masking technique is implemented as a high-pass filter and improves the sharpness of degraded images. However, the conventional unsharp masking enhances the noise component simultaneously. To reduce the noise influence, we introduce the edge information from the difference of the gradient values between two consecutive scales of the multiscale gradient. The multiscale gradient indicates the presence of image edges as the ratio between the gradients between two different scales by its multiscale nature. The noise reduction of the proposed method does not depend on the variance of images and noises. In experiment, we demonstrate enhancement results for blurred noisy images and compare with the conventional cubic unsharp masking technique.

1. Introduction

Image enhancement techniques are applied to the blurred images to enhance the sharpness and contrast of the image edges. Unsharp masking technique is one of major image enhance technique. The unsharp masking is implemented as a linear high-pass filter and improves the sharpness of degraded images. However, the conventional unsharp masking enhances noise components that are added to the blurred image simultaneously. To reduce the enhancement of noise components, the control of the unsharp masking by the edge information has been proposed as the cubic unsharp masking[1]. In Ref. [1], the edge information is defined as the squared sum of the differences of intensity along the horizontal and vertical directions of the input image. The edge information is defined as the square of the gradient of the image intensity at each pixel.

In this paper, we introduce the new edge information for the unsharp masking to improve the noise reduction capability of the cubic unsharp masking. We propose the edge information from the difference of the gradient values that are given from two consecutive scales of the wavelet transform. The multiscale gradients indicate the presence of image edges as the ratio between the gradients between two different scales by its multiscale nature. So, the enhancement by the proposed method does not depend on the variance of images and noises that are added to the blurred input image.

In experiment, we demonstrate enhancement results for blurred noisy images and comparison between the proposed method and conventional cubic unsharp masking technique.

2. Cubic Unsharp Masking

The result of the unsharp masking is obtained from the addition of the Laplacian and the input image $f(m, n)$ as

$$y(m,n)=f(m,n)+\lambda L(m,n). \qquad (1)$$

Where λ is a constant that is selected from the degree of the enhancement. $L(m, n)$ is Laplacian of the input image as

$$L(m,n)=f(m,n)-\frac{1}{4}(f(m-1,n)+f(m+1,n)+ \\ f(m,n-1)+f(m,n+1)). \qquad (2)$$

In the cubic unsharp masking proposed by Ramponi[1], the edge information $e(m, n)$ is defined from the input image $f(m, n)$ as

$$e(m,n)=\{f(m-1,n)-f(m+1,n)\}^2+ \\ \{f(m,n-1)-f(m,n+1)\}^2. \qquad (3)$$

The high-pass component of the cubic unsharp masking is obtained as the product between the edge information $e(m, n)$ and the Laplacian $L(m, n)$. The enhance result is given by

$$y(m,n)=f(m,n)+\lambda F[e(m,n)L(m,n)] \qquad (4)$$

$e(m, n)$ increases around image edges and the amplitude of the high-pass component also increases. So, the amplitude of Laplacian for image edges is larger than the planer region where the noise components appear. $F[\cdot]$ is a non-linear function which has the saturation level T as:

$$F[x]=\begin{cases} T & for \quad T>x \\ x & for \quad -T\le x\le T \\ -T & for \quad x<-T \end{cases} \qquad (5)$$

To improve the detection capability of edge region and reduce the noise influence in the enhancement result, we introduce the wavelet transform to the edge information.

3. Edge Information from the difference of multi-scale gradients

The discrete dyadic wavelet transform is defined by the inner products between the wavelet bases and an image. Usually, the one-dimensional discrete wavelet transform is computed from the discrete-time filterbanks. In two-dimensional case, the filterbanks are applied to the original image along horizontal and vertical direction. The two-dimensional wavelet transform has the property of spatial orientation selectivity. We select the two-dimensional wavelet transform that can be computed by the discrete filterbank in Fig. 1 for the edge detection and analysis[2]. In this filter bank, the horizontal and vertical edges are detected from the filter outputs separately. The J-the scale discrete dyadic wavelet transform of the original image is represented as set of the sequences:

$$\{W_j^H f(m,n)\}_{1\le j\le J},\{W_j^V f(m,n)\}_{1\le j\le J}. \qquad (6)$$

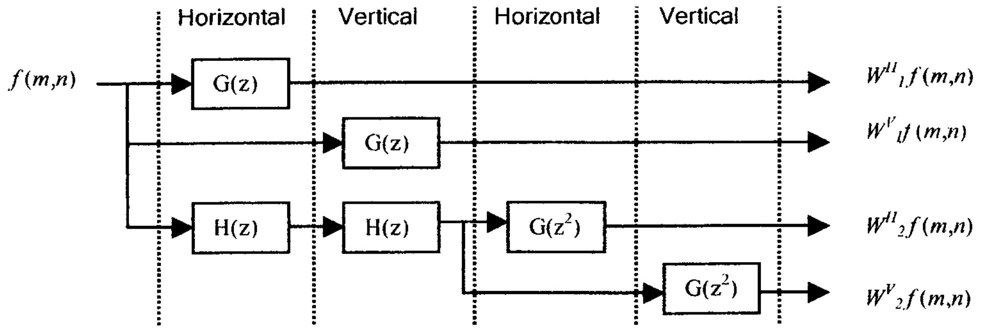

Fig.1 Filter bank structure for two-dimensional discrete dyadic wavelet transform.

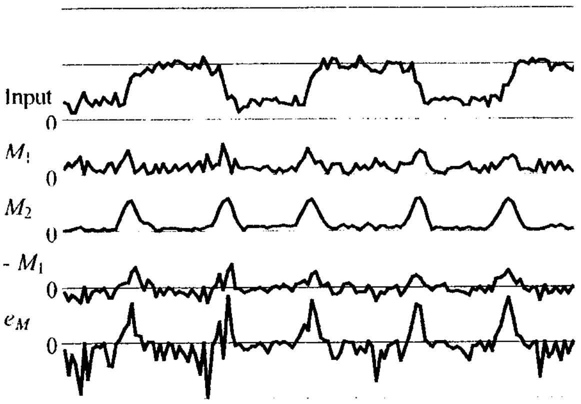

Fig.2 An example of multi-scale gradients for one-dimentional signal.

To extend the edge information $e(m, n)$ to multi-scale representation, we define the impulse response of the high-pass filter of filterbank as {-1, 0, 1}. The low-pass filter of filter bank is selected as {1/4, 1/2, 1/4}. The multi-scale gradients are defined as

$$M_j(m,n)=\sqrt{\left(W_j^H f(m,n)\right)^2+\left(W_j^V f(m,n)\right)^2}\ . \qquad (7)$$

The Ramponi's edge information $e(m, n)$ is equal to the square of the gradient at scale j=1.

The example of the multi-scale gradient for one-dimensional signal is shown in Fig. 2. The modulus maxima appear the edge positions at each scale. The modulus maxima decrease along decrement of scale at edge positions. The noise components decrease along increment of scale. In Ref. [2], the decay of wavelet transform is analyzed by the differentiability of signals.

We introduce the new edge information for unsharp masking by employing the multi-scale nature of the wavelet transforms. The multi-scale edge information $e_M(m, n)$ is proposed as

$$e_M(m,n)=M_1(m,n)\left(M_2(m,n)-M_1(m,n)\right). \qquad (8)$$

The example of the $e_M(m, n)$ is shown in Fig. 2. In the planer region where only intensity changes are occurred by the noise components, $e_M(m,n)$ is smaller than zero. In the edge region, $e_M(m,n)$ is larger than zero. The amplitude of $e_M(m,n)$ increase along the differences of intensity on edges. So, we can apply the $e_M(m,n)$ for the edge information of the cubic unsharp masking. The edge information $e(m,n)$ for the cubic unsharp masking that is given by $e_M(m,n)$ as follows

$$e(m,n)=\begin{cases} e_M(m,n) & for \quad e_M(m,n)>0 \\ 0 & for \quad e_M(m,n)\le 0 \end{cases} \qquad (9)$$

The enhance result is given by substituting Eq.(9) to Eq. (4) and Eq, (5) as same as the cubic unsharp masking.

4. Enhancement Results

In this section, we demonstrate noisy image enhancement by the proposed method. Comparison between the conventional method and the proposed method is also shown by the quantive evaluation. To examine the advantage of the proposed method, the linear unsharp masking and the qubic unsharp masking are employed as the conventional methods.

DV (Detailed Variance) and the BV (Background Variance) that are defined in Ref.[1] are employed to the quantitive evaluation of image enhancement. DV is the average value of local variance in detailed regions, such as edge which are desired to be enhanced, and BV is the average value of local variance in the background part which are not desired to be enhanced. After image enhancement, DV increases from DV of the original image. By the ideal image enhancement method that suppresses the emphasis of noise component, increment of BV which indicates the noise variance has to be smaller than the increment of DV. So, DV/BV ratio indicates the noise suppression effect of the image enhancement method.

To compare enhancement methods under the same condition, DV of results are set to the constant by adjustment of the parameter λ. Image segmentation that splits image to detailed region and background region is realized by thresholding the local variance of the original image [3]. The threshold is set as 1/4 of the threshold value which maximize the distance between two class of the local variance histogram. The original images for enhancement, the detailed region and the background region are shown in Fig.3 (a), (b) respectively. In enhancement experiment,

Table1 Relationship between noise variance of input image, detail variance and background variance.

Noise variance		DV	BV	DV/BV
$\sigma^2=50$	UM	2,279	1,467	1.55
	Qubic UM with e_1	2,138	453	4.71
	Qubic UM with e_2	2,188	471	4.64
	Proposed Method	2,319	297	7.79
$\sigma^2=100$	UM	3,282	2,585	1.27
	Qubic UM with e_1	3,168	1,208	2.62
	Qubic UM with e_2	3,154	870	3.62
	Proposed Method	3,213	512	6.27

smoothed images are obtained by low-pass filtering with the 3×3 pixel averaging.

Enhancement characteristic of the proposed method is compared with Ramponi's method noise suppression of the proposed method is examined by DV/BV ratio. The smoothed images that are added Gaussian noise of which variance are 50 or 100 are used as input images. The input image of which noise variance is 100 is shown in Fig.3(c). In each method, the constant 10,000 in Ref.[1] was used as threshold T which determines the saturation domain of $F[\cdot]$. The results given by the method edge information with $e=e_1$ that is gradient in scale 1 and $e=e_2$ that is gradient in scale 2 are also demonstrated. The λ of each method was set to approach the DV of the enhanced images to the DV obtained from unsharp masking at $\lambda=1$ as possible.

The DV, BV and DV/BV ratios of the enhanced images are shown in Table1. In any noise variance, the unsharp masking based on the proposed edge information decreases BV to about half value of BV of conventional qubic unsharp masking of which edge information is defined as e_1 or e_2. Since the qubic unsharp masking using e_2 decreases the influence of noise along scale increases, e_2 can decreases the DV smaller than DV of the qubic unsharp masking which using difference of scale 1 as edge information.

The enhancement results by the qubic unsharp masking using e_1 or e_2, and the qubic unsharp masking based on the multiscale edge information e_M are shown in Fig.4. In Fig.4, the qubic unsharp masking based on proposed edge information decrease background noise than the qubic unsharp masking based on the single scale edge information. Part of Fig.4 are shown in Fig.5, absolute of high-pass component that are added to input images by each enhancement methods are shown in Fig.6. In Fig.6, the maximum amplitude is shown as black, white pixels indicate as zero.

Comparing with the Rampomi's qubic unsharp masking based on gradient at scale 1, the background noise is decreased in the enhancement result by the qubic unsharp masking based on gradient at scale 2. However, in the result that given by gradient at scale 2, the noise components around edges are emphasized. In the result given by proposed edge information, only the regions that are enhanced are restricted around edges that are enhanced target.

Fig. 3 (a)Original image, (b)Regions for evaluation: (black)detail region and (white)background region and (c)Input blurred image under Gaussian noise (variance 100)

By the above experiment, the enhancement method using proposed edge information can realize suppression of noise better than the enhancement method using edge information which introduced from single scale, and has enough spatial resolution to extract only the edge region.

5. Conclusion

In this paper, we introduced the new edge information for the unsharp masking to improve the noise reduction capability of the cubic unsharp masking. We proposed the edge information from the difference of the gradient values between two consecutive scales that are given from the wavelet transform. By the proposed edge information, the simple nonlinear operator can split the input image to detailed and background regions. So, noise reduction property of the enhancement method based on the proposed information dose not depend on the variance of the input images and noises. We demonstrated that in experience, the enhancement by the proposed method realized the noise suppression superior than conventional methods.

(a) UM

(b) Qubic UM (scale 1)

(c) Qubic UM (scale 2)

(d) Proposed method

Fig.4 (a)UM, (b)Ramponi's qubic UM, (c)Qubic UM using gradient planes at scale j=2, (d) Proposed method.

(a) UM

(b) Qubic UM (scale 1)

(c) Qubic UM (scale 2)

(d) Proposed method

Fig.5 Parts of the enhanced results in Fig.4.

(a) Qubic UM

(b) Qubic UM (scale 2)

(c) Proposed method

Fig.6 Absolute of highfrequency components which are obtained in Fig.4

References

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