

# An Improved Image Ringing Evaluation Method with Weighted Sum of Gray Extreme Value

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**Abstract:** Blind image restoration algorithm usually produces ringing more obvious at the edges. Ringing phenomenon is mainly affected by noise, species of restoration algorithm, and the impact of the blur kernel estimation during restoration. Based on the physical mechanism of ringing, a method of evaluating the ringing on blind restoration images is proposed. The method extracts the ringing image overshooting and ripple region to make the weighted statistics for the regional gradient value. According to the weights set by multiple experiments, the edge information is used to characterize the details of the edge to determine the weight, quantify the seriousness of the ring effect, and propose the evaluation method of the ringing caused by blind restoration. The experimental results show that the method can effectively evaluate the ring effect in the restoration images under different restoration algorithms and different restoration parameters. The evaluation results are consistent with the visual evaluation results.

## 1. Introduction

In the process of optical imaging, the flaw of optical system, atmosphere turbulence, and the rapid movement of target object cause image's degradation phenomena which indicates that the reduction of picture contrast and definition and the smoothing of texture's marginal area, etc. Image blur restricts the acquisition of image's real information and affects the application value in engineering practice. Aiming at this problem, various image restoration algorithms emerge in response to the proper time and conditions, such as, Wiener filtering, L-R, total variation and wavelet, etc.

Restoration algorithm regards image blur's kernel function as the input, but its actual system has complex working condition, so the fuzzy kernel function is difficult to get directly, thus, it needs to



estimate the kernel function according to the condition of image and then make the blind restoration, therefore, the evaluated error of this kernel function can directly affect the final restoration. When the evaluated error is larger, the restored image may produce ring effect which shows the periodic ripple at the sharp edge of image, resulting in severe reduction of restoration effect.

Existing universal evaluating algorithm is mainly for PSNR of noise and SSIM of structure, but both of them are not designed for ringing. Based on the problem of image ringing caused by image restoration, this paper analyzes the relationship between evaluated error of fuzzy kernel in blind restoration algorithm and seriousness of ring effect, puts forward with the evaluating algorithm<sup>[1]</sup> of ring effect based on this, and verifies evaluation methodology based on simulation experiment to provide suggestion on optimization for design and application of image blind restoration algorithm.

## 2. Ringing mechanism and its impact analysis on image quality

### 2.1 Ringing mechanism

When the step signal passes through the low-pass filter, it will generate the periodic oscillation distortion, and the image signal shows that there is band or ring artifact like a “shadow of ghost” near the edge of the image, thus, original edge’s response signal will form overshooting firstly, and then jump to the steady state and generate the first ripple, and then it swings back and forth near the steady state; overshooting and continuous ripple appeared later are collectively referred to ring effect. Its essence is the Gibbs effect<sup>[2]</sup> produced in the airspace-frequency domain conversion.

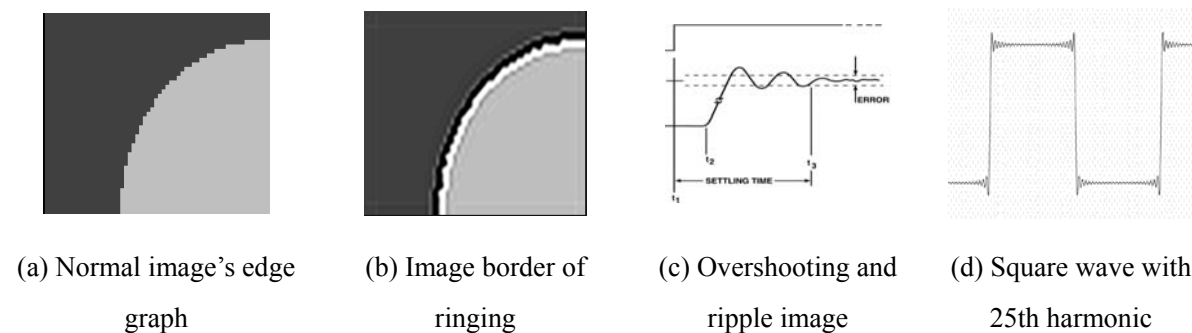


Fig.1 Ringing performance and the square wave diagram with different harmonics

When using Fourier series<sup>[3]</sup> to express step function, the overshooting will appear in the jump function, and the overshooting will not disappear with the increase of Fourier series. Figure 1-d, show harmonic (the height is  $\pi/4$ ) and square wave, which all appear overshooting and ripple in the discontinuous jump, the Fourier expansion is

$$\sin(x) + \sin(3x) + \sin(5x) + \dots \quad (1)$$

$$f = \begin{cases} \pi/4 & 2n\pi \leq w \leq (2n+1)\pi \quad \& n \in N^+ \\ -\pi/4 & (2n+1)\pi \leq w \leq (2n+2)\pi \quad \& n \in N^+ \end{cases} \quad (2)$$

Where  $w$  means frequency and the square wave has jumps with the height of  $\pi/2$  at every integral multiple. It can be seen that with the increase of the number of items, the approximate error will be decreased on the width and the energy, but it still converge to the fixed height. The following formula indicates explicit expression of height limit of calculation error, it can be seen that the sum of Fourier series is more than the height of the square wave, and its multiple is:

$$k = \frac{1}{2} \int_0^\pi \frac{\sin t}{t} dt - \frac{\pi}{4} = \frac{\pi}{2} \times (0.089489872236...) \quad (3)$$

It also can be seen that the other end of the square wave will undershoot the same energy.

## 2.2 Ring effect caused by image's blind restoration

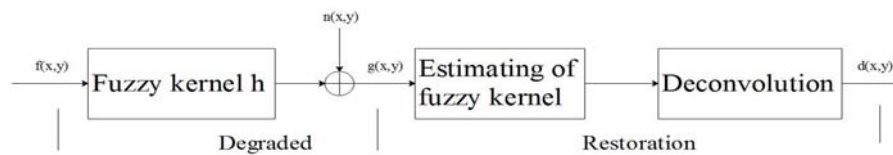


Fig.2 Image degradation and recovery process

As shown in figure 2, the degeneration of the image is mathematically represented as:

$$g(x, y) = f(x, y) * h(x, y) + n(x, y) \quad (4)$$

In the above formula,  $g(x, y)$  means degraded image;  $f(x, y)$  is the original image, and  $h(x, y)$  is fuzzy kernel, namely, the point spread function (PSF);  $n(x, y)$  is the additive noise. Blind image restoration is the process<sup>[4]</sup> of approximate solution  $f(x, y)$  through estimating  $h(x, y)$  and  $n(x, y)$ . Considering the huge computational burden of airspace deconvolution, usually it needs to convert image signal to frequency domain by using the fast Fourier transform to solve the formula (4). Its core issue is to make the inverse filtering in the frequency domain:

$$I(x, y) = F^{-1} \left( \frac{G(u, v)}{\hat{H}(u, v)} \right) \quad (5)$$

In the above formula,  $I(x, y)$  is the approximate solution of  $f(x, y)$  under in the frequency domain, and  $G(u, v)$  refers to the frequency domain of degraded image  $g(x, y)$ ;  $\hat{H}(u, v)$  is the estimated value of point spread function (PSF), that is, the expression of frequency domain of fuzzy kernel:

$$\hat{H}(u, v) = H(u, v) + \Delta H(u, v) \quad (6)$$

$H(u, v)$  is the optical transfer function (OTF) in the process of practical degradation, and  $\Delta H(u, v)$  is evaluated error of fuzzy kernel. Due to  $H$  has the great matrix condition number, even a small perturbation will seriously affect the solution of  $I(x, y)$ , and from formula (4) and (6), it can be seen that the existing disturbance mainly includes the noise  $n(x, y)$  and the evaluated error  $\Delta H(u, v)$ .

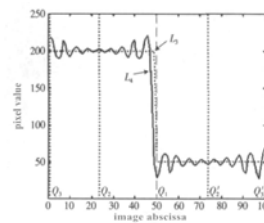
In conclusion, when there is deviation of fuzzy kernel in the process of the blind restoration,

resulting in the restored image exists in excessive restoration, on the one hand, the fixed ringing phenomenon in the process of airspace-frequency domain transformation will be amplified; On the other hand, due to the gray level distribution of ringing has close connection with image information, regularization item has less constraint for it, and in order to avoid noise amplification, it needs to adjust the regularization item and further inhibit the high-frequency information in the restored image, causing ringing phenomenon is more obvious.

### 3. Evaluation index and method of ringing

It can be seen from the formation mechanism of ringing that conventional image features can not provide effective support for the extraction of ringing characteristics. The image features of ringing are further analyzed in the following paper.

#### 3.1 Basic thought for the evaluation of ringing



(a) Performance of ring effect at the edge of the image      (b) Restoration produces the ringing pixel curve

Fig.3 Performance of ringing at the edge of the image and pixel curve graph

Figure 3 is ringing of image edge and its response curve caused by image's blind restoration the. In edge response curve, the abscissa  $Q_2$  to  $Q_2'$  indicates gray level of pixel that the edge of the figure 3-a summarizes along with gradient direction, and the abscissa  $Q_2$  to  $Q_1$  correspond to the white edges of the figure 3-a on the right side, and  $Q_1$  to  $Q_2'$  correspond to black edge of the figure 3-a on the left side;  $L_4$  refers to a dramatic change, corresponding to the white and black junctional zone. As you can see, the waveform has dramatic change of gray level at  $L_3$ , displaying the diminishing performance in waves, and the closer to the  $L_4$ , the more serious the oscillation, on the contrary, the farther away from the wave, the oscillation is leveling off.  $Q_2$  to  $Q_2'$  in the image indicates the influence of ringing, to represent the image edge details<sup>[5]</sup> through statistical image's edge information value, at the same time, it becomes the weighting coefficient of overshooting and ripple.

Based on the above analysis, the evaluating algorithm of ringing is proposed.

#### 3.2 Evaluating algorithm of ringing

We use formula (7) to construct Gaussian filter<sup>[6,7]</sup>, and respectively smooth the original and restored image in row and column according to the formula (7), to further reduce the influence of

noise and improve the precision of the results:

$$\tilde{g}(x) = \frac{\exp(-x^2 / 2\sigma^2)}{2\pi\sigma^2} \quad (7)$$

Due to the ring effect is mainly focused on the edges of the image, so using formula (8) and formula (9) to respectively mark the edge of original image  $O$  and restored image  $R$ , namely, respectively calculate the gradient magnitude and direction at the sharp edge of the image:

$$M(x, y) = \sqrt{k_x^2(x) + k_y^2(y)} \quad (8)$$

$$H(x, y) = \arctan[k_x(x, y) / k_y(x, y)] \quad (9)$$

Among them,  $k_x$  and  $k_y$  are the difference result at the direction of the row and column respectively. At the same time, mark  $\hat{O}$  and  $\hat{R}$  for the mark of edge of  $O$  and  $R$ . This method can extract the ringing overshooting and ripple inside the sharp edge and neighborhood of the image; due to the extraction results have a certain width, in order to determine the gray extremum inside ringing area, it needs to find strong edge along the gradient direction and each local maximum inside neighborhood; also it uses the linear interpolation method <sup>[8,9]</sup> of formula (10) to remove the non-maximum at the gradient direction:

$$P_i = \left(\frac{dx}{dy}\right)I_1(x, y) - \left(1 - \frac{dx}{dy}\right)I_2(x, y) \quad (10)$$

In the above formula,  $I_i(x, y)$  and  $i = 1, 2, 3, 4$  represent neighborhood value marked in  $\hat{O}$  and  $\hat{R}$  at the four directions of extreme points  $45^\circ, 135^\circ, 225^\circ$  and  $315^\circ$ , at the same time, mark  $\hat{O}$  and  $\hat{R}$ , namely the image after maximum inhibition as  $O\%$  and  $R\%$ , after the above calculation  $O\%$  and  $R\%$  contain the most severe pixel of gradient change. Because the results extracted by this process usually exist breakpoints, supplement it with morphological expansion algorithm in the formula (11), at the same time, use the formula (12) to calculate the information entropy  $R\%$  and  $O\%$ :

$$\hat{O}(x, y) = \int_0^{n-1} \int_0^{n-1} \max(\tilde{O}(i+x, j+y) + B(i, j)) dx dy \quad (11)$$

$$NEny = \sum_i^{255} q_i \log q_i \quad (12)$$

In the above formula,  $B$  is structural element and  $O_i$  and  $q_i$  are the probability of an element. Due to the image's sharp edge and ring effect are characterized by gray mutation in the images, in order to eliminate the influence of the image content itself, make the logical exclusive operation for the edge extraction result of restored image after  $\hat{O}$  and smoothing to remove the non-ringing part, and get the gradient image  $T(x, y)$  which only included in ringing area:

$$T(x, y) = \hat{O}(x, y) \odot \hat{R}(x, y) \quad (13)$$

In above formula,  $\odot$  refers to logical exclusive operation. We can see from figure 5-a that ringing will

be more obvious when it is closer to the image edges in the image; in figure 5-b, the edge also present the diminishing oscillation state accordingly, so the factors which reflect the severity of ringing is not only including ringing affected scope, but including gray level in turbulence inside the ringing area, so based on the results of the above extraction, it needs to extract maximum overshooting amplitude in ringing area.

Make expanding operation for the edge of the tag result  $\hat{O}$  obtained from (8) (9), to make the expanding area cover the ringing area and make the binarization for this image, thus, use the image as a template to get the maximum amplitude of screening ringing in  $\hat{R}$  calculated from formula (11):

$$\bar{O}(x, y) = \text{Bin} \left[ \int_0^{n-1} \int_0^{n-1} \max(\hat{O}(i+x, j+y) + \hat{B}(i, j)) dx dy \right] \quad (14)$$

$$T_{\max}(i, j) = \max_{i, j} (\bar{O}(i, j) \cdot \hat{R}(i, j)) \quad (15)$$

In above formula,  $\text{Bin}[\cdot]$  refers to binarization processing, and “ $\cdot$ ” means dot matrix. On this basis, we can use weighted summation of the ringing region’s gradient value and the large amplitude to describe the change of image gradient caused by the image ringing.

$$S = \sum_1^n \sum_1^m T_{\max}(i, j) + (N E n y / O E n y) * \sum_1^n \sum_1^m T(i, j) \quad (16)$$

Finally, in order to further characterize the proportion of false edge generated from ringing in the restored image, use  $S$  and  $\hat{R}$  to define ringing intensity’s evaluation indexes:

$$C = \sum_{n=1}^N \frac{1}{\hat{R}} |S - \hat{R}| \quad (17)$$

## 4. Experimental verification and analysis

### 4.1 Experimental scheme

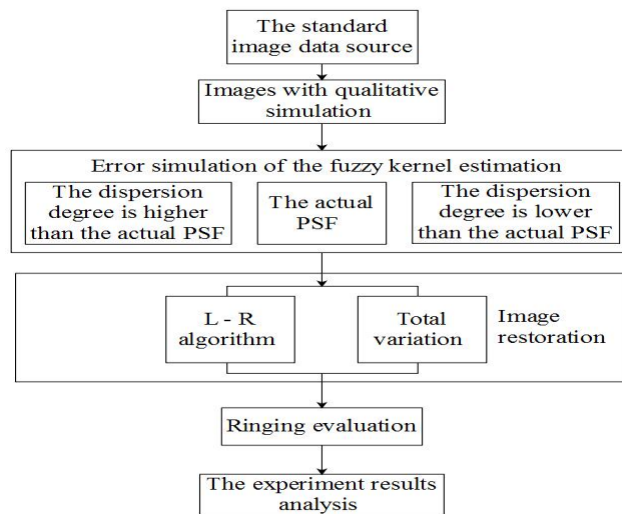


Fig.4 Experimental flowchart

In this paper, it adopts simulation experiment to verify the effectiveness of the algorithm, The above chart of the experimental scheme is shown in figure 4.

In order to ensure the accuracy of the experimental results, the image in this paper is selected from the LIVE database and the TID2008 image library. In order to test the sensitivity and applicability of the algorithm with different image content, the content of experiment includes portraits, still life, landscapes, a total of 15 images with rich edge and texture information, part of the sample image is shown below.

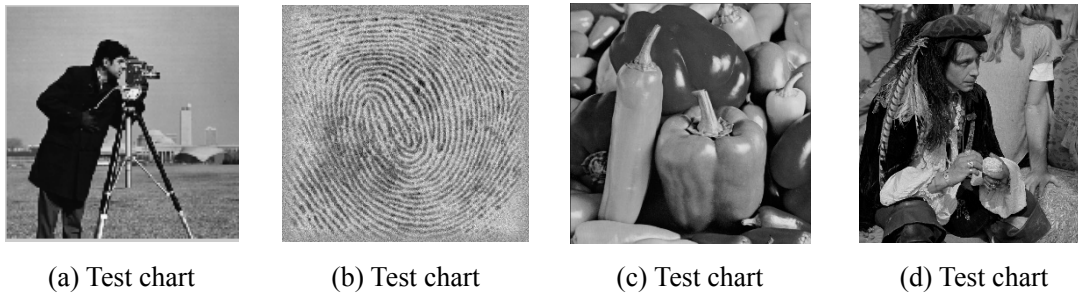


Fig.5 Examples of experimental sample images

#### 4.2 Experimental result and analysis

Figure 6-a is the sample image selected from the standard database, and figure 6-b is the degraded image obtained by adding the Gaussian blur with parameter  $\sigma=0.8$  to the sample image. It can be seen clearly that due to the different errors in PSF during restoration, the ringing with different levels are produced in the image.

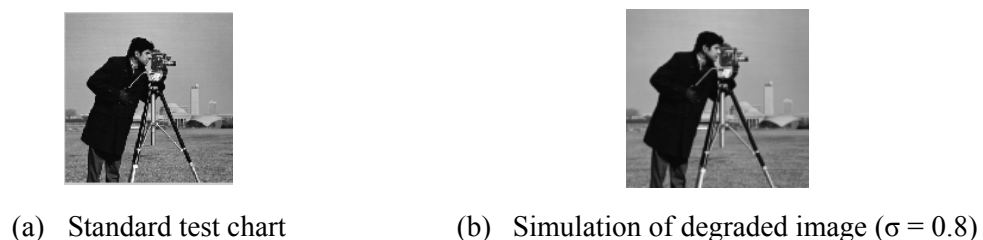


Fig.6 Standard and degraded images

Figure 7-a, 7-c, 7-e and 7-g are the curves after the four text images adopt SSIM evaluation result after restoration by using two kinds of algorithms; abscissa in the figure is the parameter used PSF, and ordinate is the evaluation value obtained by SSIM. We can see from the figure that four curve is decreasing gradually with the increase of fuzzy kernel' estimation error, but when the fuzzy kernel error is larger, the evaluation result trends to be stable, and the evaluation results no longer changes, which is inconsistent with the subjective observation of experimental images.



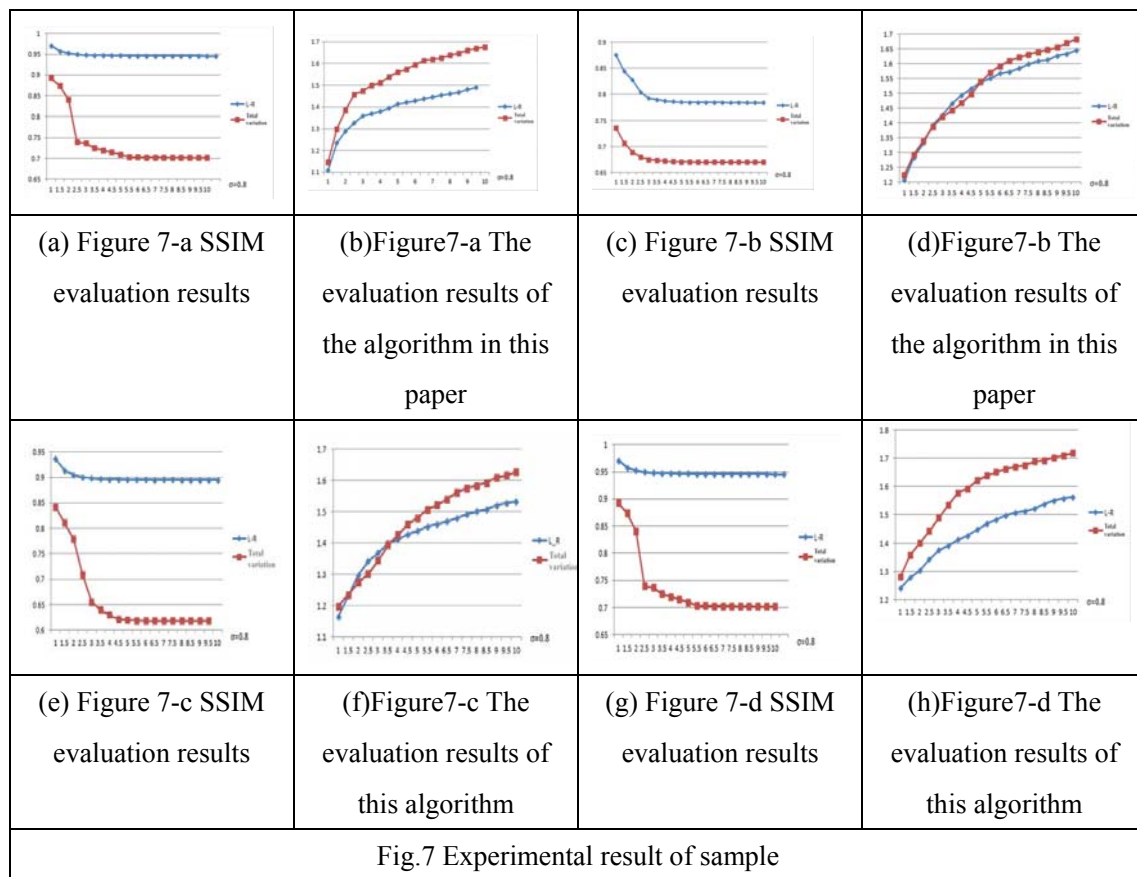


Figure 7-b, 7-d, 7-f and 7-h are the curves of evaluation result after the four text images adopt algorithm after restoration by using two kinds of algorithms; the evaluation results is gradually increasing with the increase of fuzzy kernel' estimation error, and when the error in the fuzzy kernel is larger, it can still accurately measure, which accords with the experimental images of subjective observation. So the algorithm in this paper can effectively evaluate different restoration algorithm and existing ring effect in restored image and different original parameters, at the same time, it also can prove that in the process of image's blind restoration, when the estimate of the fuzzy kernel's dispersion degree is higher than the actual one, the restored image can produce ring effect, and its serious degree increases along with the augment of estimation error.

## 5. Conclusions

Starting from the mechanism of ring effect caused by blind restoration, the paper proposed a evaluating algorithm on the basis of the weighted sum of gray extreme value and image's ring effect by analyzing the ring effect's gray level and structural feature in the image; also, it verifies the validity of algorithm through the simulation experiment method and by using different sample image and restoration algorithm. The experimental results show that this algorithm can effectively evaluate the ring effect of different restoration algorithms and existing ring effect in restored image and different



original parameters. When the dispersion degree of the fuzzy kernel during blind restoration is higher than actual one, the restored image will have excessive restoration, which results in the obvious ring effect.

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