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Simulation Study of Effects of the Blind Deconvolution on Ultrasound Image

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Abstract. Ultrasonic image restoration is an essential subject in Medical Ultrasound Imaging. However, without enough and precise system knowledge, some traditional image restoration methods based on the system prior knowledge often fail to improve the image quality. In this paper, we use the simulated ultrasound image to find the effectiveness of the blind deconvolution method for ultrasound image restoration. Experimental results demonstrate that the blind deconvolution method can be applied to the ultrasound image restoration and achieve the satisfactory restoration results without the precise prior knowledge, compared with the traditional image restoration method. And with the inaccurate small initial PSF, the results shows blind deconvolution could improve the overall image quality of ultrasound images, like much better SNR and image resolution, and also show the time consumption of these methods. it has no significant increasing on GPU platform.

1. Introduction

Nowadays, ultrasound has been widely used in biological and medical fields, including ultrasound diagnosis and ultrasound therapy. Ultrasonic diagnostic imaging system is processed by the spread of the impact beam and atmospheric turbulence, mechanical interference and detection of the object relative to the ultrasonic probe of the relative movement, which will lead to the formation of defocus blurred image that has taken place. Thus, making the system-generated lateral resolution of ultrasound images has been reduced, causing the image degradation [1]. Meanwhile, the imaging system, there is still uneven defocusing of the problem: In the beam of the focal plane to gather better-performance, but with the beam from the focal plane distance, the spread is more and more serious; and the unfocused image is more serious. Image restoration is one of the most efficient reverse processing technologies for image quality degradation [2].

Compared to the other medical imaging systems (like CT, MRI, and X-ray), one obvious defect in ultrasound imaging system is the low spatial resolution which would make the clinical diagnosis for some diseases difficult. This is one essential problem for ultrasound imaging system. Due to each ultrasonic beam with a certain size, the limited bandwidth of the energy converter and the receiving circuit, even if it is a point in the space (actually impossible in the human body), it will be the speckle with a certain size. Speckle means the spatial resolution is degraded [3]. If each processing step of ultrasound imaging system could obtain accurate definition, it is possible to use the inverse filtering method to restore the degraded image as much as possible. In the ultrasound imaging system, the B-mode image can be considered as the results of the convolution of the point spread function (PSF) and the original signal [4]. The point spread function is a function of the system parameters and the spatial variable operators [5] [6]. Thus, the degradation of the quality of ultrasound images, mainly comes from the two aspects: one is the noise presented on the image, generally considered it as additive noise model; In the other aspect, the main lobe of the point spread function will become boarder with the increasing distance of the mismatched focus, which will cause the image energy diffusion and decrease resulting in image resolution degradation [7].

In order to eliminate the degradation of the image quality, many different images restoration methods have been proposed. However, because the recovery quality evaluation criteria are not unified, different researchers use different techniques in this subject. Traditional ultrasound image restoration methods are often based on linear restoration method, which is based on the assumption that the system point spread functions are known and utilized the inverse filter to restore the degraded image. Although the point spread function belongs to the scope of system parameters, but in the actual system, it will be impacted by some other factors such as media speed of sound. It can’t be accurate definition. Besides of the linear image restoration algorithms, some nonlinear and iterative image restoration algorithms like Lucy-Richardson methods are also presented. In [8], a unified algorithm for performing blind deconvolution of a noisy degraded image was present. With the help of genetic algorithm, it is proposed a unified framework for restoration process for deblurred images [9]. Blind deconvolution gives a restoration operation of the blurred image in case of no prior knowledge of the system PSF presented.

The main purpose of this paper is to demonstrate the use of blind deconvolution for the ultrasound image restoration and compared with traditional image restoration methods by SNR, image resolution and time performance. The paper first built a computer simulation of the ultrasound image noise mode to research an appropriate way of improving the quality of ultrasound imaging using CUDA (Compute Unified Device Architecture). The Gauss convolution is based on the GPU parallel methods [10]. By adding noises to the simulate images, this paper research how to use the blind deconvolution for the ultrasound image restoration. After some experimental tests, we prove the blind deconvolution method can be applied to the ultrasound image restoration with small initial PSF, which could improve the overall image quality of ultrasound images, lead to much better image resolution, and be easier to be applied, Compared with Lucy Richardson (L-R) methods, and also without obvious time consumption increasing.

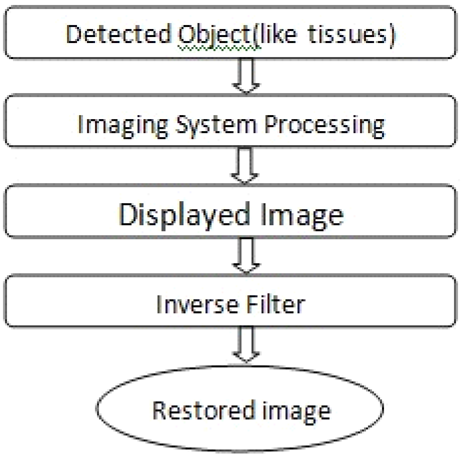

Fig.1. The flowchart of the ultrasound image restoration

2. Experimental Method

2.1. Ultrasound Image Restoration Model

Image restoration is the inverse process of image degradation and try to restore the degraded images as much as possible. In the ultrasound imaging system, the detect object could be considered as the system input and the system output is the display image. In ideal conditions that means no noise, the system is being absolutely stable, no interference and so on; the output of the ultrasound imaging system can be considered as the convolution of the input images and the PSF. Thus, the ultrasound imaging scene is represented by the distribution of tissue scatters s(x, y), then the image g(x, y) can be given by the following equation:

$$g(x, y) = h(x, y) \otimes s(x, y) \qquad (1)$$

where h(x, y) is a 2-D PSF of the system, and the PSF of a two-way beamforming can be obtained by calculating the peak of the envelope of the k-th signal related to an observing point (xk, zk), see Eqn. (2).

$$h_k(t) = \sum_{j \in RX} \sum_{i \in TX} a_i b_j P(t - \tau_i - \tau_j - \frac{R_{i,k}}{c} - \frac{R_{j,k}}{c}) \qquad (2)$$

Where *c* is the sound speed of a homogeneous tissue, a_i, b_j are apodization functions, and $R_{i,k}$ is the distance between the transducer element *i* and the observing point (x_k, z_k).And τ represents the transmit and received delay respectively, defined in Eqn. (1), and *P* represents the pulse response of each element.

Using FFT (Fast Fourier *Transformation*), one can obtain the corresponding equation of Eqn. (1) in frequency domain:

$$G(x, y) = H(x, y) * S(x, y) \qquad (3)$$

where G(x, y), H(x,y) and S(x,y) are the FFT output of *g(x, y)*, *h(x,y)* and *s(x,y)*. Therefore, the inverse process in frequency domain is G(x, y) / S(x, y) when we can get the *h(x, y)* based on the imaging system feature. If so, we could use the deconvolution on the degraded image to restore the original image. Fig.1 shows the flowchart of the image restoration. Image restoration is an inverse problem, usually the solution of the inverse problem is not unique, even there is no solution, and therefore image restoration is quite difficult. Especially, in ultrasound imaging system, as it will be involved with noise, see Eqn. (4). And it is also difficult to get the accurate *h(x, y)*. Moreover, if the value of H(x,y) is small, the value of S(x,y) will be large and the significant error will come up with slight changes in the value of H(x, y). In order to obtain a valid solution or an optimized solution with some constrains, we require an evaluation criterion to measure the approximation degree of the restored image and the real image. To attain this, the priori knowledge or the constrain for solution are needed**.**

2.2. Blind Deconvolution for Ultrasound Image Restoration

The most difficult problems in image restoration process is how to get the precise system PSF that is used as an essential parameter in the restoration algorithm. The linear image restoration algorithms like Wiener filter, some nonlinear and iterative image restoration algorithms like L-R method all require the prior knowledge of PSF. In this paper, we study the use of the blind deconvolution algorithm in ultrasound image restoration, which utilize the degrade image to estimate both the system PSF (also inverse solution of this PSF) and the original clear image. Blind image restoration is the process of estimating both the true image and the blur from the degraded image characteristics just with partial information about image system. It is different from the traditional restoration ways which assume the system PSF *h(x, y)* is prior known. And in the ultrasound imaging system, to obtain the a priori information to the PSF it is relatively difficult, and it is usually unknown or imprecise. Thus, the advantage of the blind convolution algorithm is that we could still restore the blurred image in the case of the absence of any prior knowledge of the degraded image. In the system application, we usually assume that the signal transmission of the image system is linear. It can be described as follow:

$$g(x,y)=h(x,y) \otimes s(x,y)+n(x,y) \qquad (4)$$

Where, *n(x, y)* is the additional *noise* model.

Based on Eqn. (4), we could carry on the image restoration. The blind deconvolution refers to the task of separating two convolved signals, h and s, when both the signals are either unknown or partial known. We can use the partial information, here the initial PSF, to be an optimality criterion, which is maximized to find the estimates of the components. It is an iterative restoration method. Each iteration can increase the likelihood of the solution and the clear image. With the increasing number of iterations, the solution will converge at a specific point and we will ultimately have the maximum likelihood solution.

In order to achieve more accurate estimates of the blind deconvolution, the initial PSF should be selected carefully. In the other hand, the *number* of iterations and Gauss convolution are huge computation. For the most of case, the small initial PSF will obtain a convincing result and low time consumption. Fig.2 shows the procedure of the blind deconvolution method.

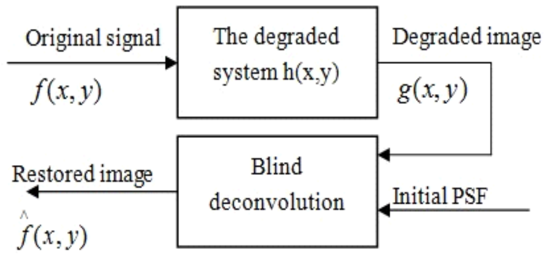

Fig. 2. The procedure of the blind convolution method.

2.3. *The Evaluation Criteria of Image restoration*

For the assessment of the validity of the image restoration method, the objective image quality evaluation method is usually to create a model based on the human eye's subjective vision, and calculate the image quality with this model. For ultrasound images, the doctors tend to be more attention to detail resolution and image noise. In this paper, we use the signal to noise ratio (SNR) to evaluate the restoration results, which is calculated as follows:

$$SNR = 10\log\frac{\sum_{i,j\notin D}(g(x,y)-f(x,y))^2}{\sum_{i,j\notin D}(\hat{f}(x,y)-f(x,y))^2} \tag{5}$$

Where $\hat{f}(x,y)$ is the restored image, *f(x, y)* is the original image, *g(x, y)* is the degraded image and *D* is the image field.

For the actual ultrasound image, the SNR is not easy to calculate and it will be not accurate. The histogram of one image is the *occurrence* probabilities of the image pixel gray-scale. It depicts the distribution of each gray level in the image. It means the histogram shows the contrast resolution of the whole image. It could be a quality factor to measure the ultrasound images. Thus, besides of the SNR, the histogram is also used to slow the resolution change of the restored image. And the runtime is also an important performance index for real-time system.

3. Results and Discussion

This section presents initial validation and benchmark results of the restoration algorithm. Fig.3 shows the simulated ultrasound image with its histogram. We setup a Gauss function with the size of 7×7 and the standard deviation 10 to blur the original image of Fig.3.

During blind deconvolution image restoration, one should usually choose a smaller point spread function (PSF) as the initial value to restore the image and at the same time estimate and restore the PSF of the degraded image. Here, we set a 3 × 3 PSF that is smaller than the Gauss blur mask to apply the blind convolution on the degraded image in Fig.4. The restored image with its histogram is showing in Fig.5 and the SNR is 0.63. Fig.6 shows a bigger initial PSF (11×11) as the experimental comparison to see the impact of the initial PSF in the restoration and the SNR is -3.34.

Also, we set the actual PSF of the original image (Fig.3) to carry on the blind convolution to restore the image. The restored image with its histogram is showing in Fig.7 and the SNR is 2.83.

Fig.8 and 9 shows the results of the L-R methods with different iterations. Obviously, it doesn't get better restoration quality just by increasing the number of iterations.

From Table 1, the runtime has no significant differences between L-R and blind convolution methods (tested on GTX 750Ti Graphic card). For blind convolution methods, the actual initial PSF decreases iteration number and the small initial one has small Gauss window size, so they are better than the bigger one.

In the other hand, we could also estimate and obtain the restored PSF during the procedure of the blind deconvolution image restoration. Fig.10 (1) shows the actual PSF of original image, Fig.10 (2) shows the restored PSF with smaller initial PSF and one for bigger initial PSF in the Fig.10(3). Fig.10 (4) shows the restored PSF with initial PSF using the actual one.

The main difficulty for the image restoration in the ultrasound system is that the related system parameters are hard to get. So, some of the traditional image restoration algorithms premising the prior knowledge such as Wiener filter, L-R restoration method, results in the distortion of image restoration and even can't restore the degraded images at all. The experimental results in this paper show that the blind convolution algorithm could be used for ultrasound image restoration. It could still obtain the accepted restored image quality without any precise prior knowledge and the SNR of the restored image with the coarse selected PSF is close to the one with the real system PSF. Thus, the blind convolution algorithm just caters to the characteristic of the ultrasound imaging system that often doesn't know the precise system information such as the noise model, the PSF and so on. In the actual imaging system requirement, one could use a smaller PSF as the initial condition to restore the degraded image and not to arduously select the quite precise one.

Table 1. Comparison of SNR

Method	SNR	time(ms)
Blind conv with small initial PSF	0.63	8.56
Blind conv with big initial PSF	-3.34	16.5
Blind conv with actual initial PSF	2.83	11.2
L-R with 5 iteration	-1.78	5.25
L-R with 15 iteration	-6.97	15.3

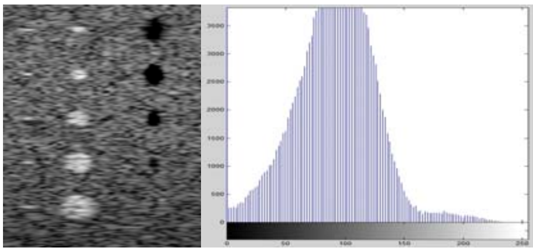

Fig. 3. The simulated B-mode image and its histogram

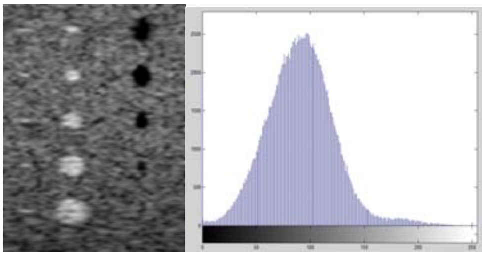

Fig. 4. The degraded image after adding Gauss noise and its histogram

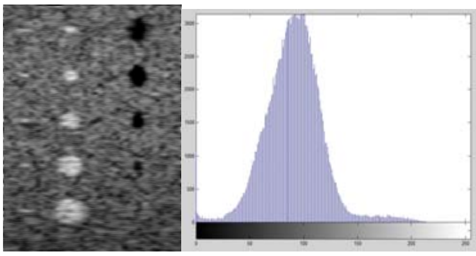

Fig. 5. The restored image and its histogram with the smaller initial PSF

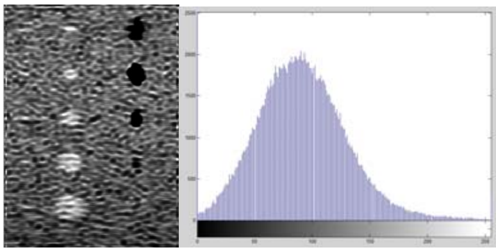

Fig. 6. The restored image and its histogram with the bigger initial PSF

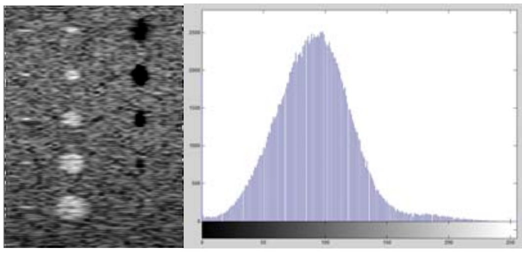

Fig. 7. The restored image and its histogram with the actual PSF

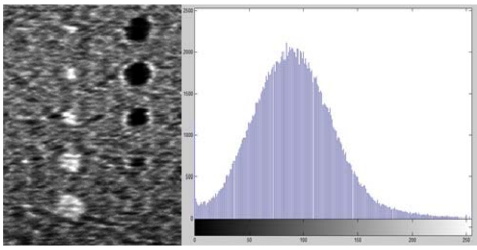

Fig. 8. The restored image and its histogram with L-R method (iteration is 5)

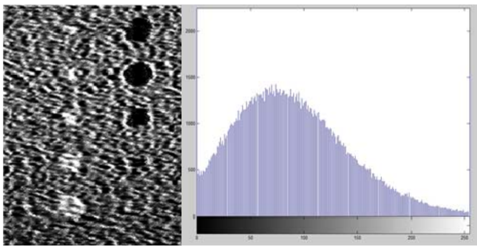

Fig. 9. The restored image and its histogram with L-R method (iteration is 15)

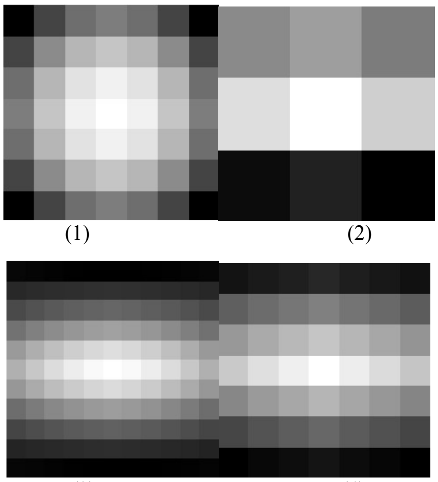

Fig. 10. The actual PSF and restored PSFs

4. Conclusion

This paper is focusing on how to use image recovery technology to improve the quality of ultrasound images. By the image histogram parameters and signal to noise ratio, we can see that, blind deconvolution methods can still effectively restore the degraded ultrasound image without the prior information like the image degradation model, noise model and so on. This conclusion is consistent with the characteristics of ultrasound imaging system that doesn't have explicit noise model. Moreover, without significant time consumption increasing, it can be used in the real-time ultrasound system. However, the restoration results of the blind deconvolution method are also related to the initial PSF. The better the initial PSF is, the better the SNR and the restoration results are. Thus, further work could continue to research for some relative points: 1) how to apply the blind deconvolution method in the ultrasound system application; 2) estimate the PSF more accurately to obtain more stable restoration consequent.

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