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The Application of Nonlinear Filtering in Reducing Noise and Enhancing Radiographic Image

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Abstract: - Real-time digital radiography is an important developmental tendency for radiographic inspection and diagnosis technique, and enhancement of image is the key to improve resolution and sensitivity of radiographic inspection. In this paper, the algorithm and character of Rank-Order filter is discussed with great emphasis. Rank-Order filter is one of nonlinear filter, All the methods are used to process radiographic image, and the result illustrate that linear filter can reduce noise but corrupt edge. Rank-Order filter can reduce noise as well as preserve the detail and has evidently effect on improving image quality.

Key-Words: - Radiographic Image Denoising; Nonlinear Filtering; Linear Filtering

1 Introduction

Real-time digital radiography is a very important means for NDT .In the test system of real-time digital radiography, because of the noise from quanta and gurgitation or a lot of any other reasons .which resulted in weak image signal,low SNR,low definition,bad contrast, which also influencing the analysis and comments of the tested component by radiographic image. Enhancement of image technology which based on the linear filtering has a lot of advantages, such as perfect theory foundation, simple mathematic algorithm, implemental hardware easily and so on, Linear filtering always play an very important role in the area of image filtering, but when it is used for processing the radiographic image. We can find that it will corrupt edge and lose the detail information of the image, and all of the above disadvantages are the side effect of reducing noise by using linear filtering. Rand-Order filtering not only has the simple algorithm,good flexibility,be prone to understand and realize but also has the function such as smoothing image,enhancing edge,restraining noise,saving detail etc[1-9].

2 Source of radiographic image noise

Fig.1 shows the imaging system, which adopted by this paper, the system has a prominent character that can be fit for imaging test with different radiography energy.

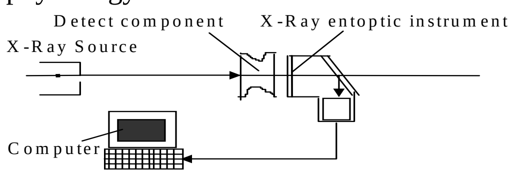


Fig.1 X-ray Digital Imaging System

From Fig.1 we can see that the noise of digital radiography imaging system is caused from each part of the imaging system, the main noise comes from as following: quanta noise which is resulted from X-ray source, and mechanic noise which is resulted from asymmetry of transformation screen.

3 Linear processing approach of radiography image noise

Linear noise reduction includes neighborhood average in spatial domain and filtering process in frequency domain, all of these methods are general called image smoothing processing. Smoothing is a common method in noise reduction of image processing, and in order to reduce noise by the average of the gray levels in the neighborhood pixel, smoothing which is called neighborhood average in special domain, but called low-pass filtering in frequency domain. Object of radiographic imaging testing is micro-structure (such as gaps ,air hole), so linear smoothing will blur these information certainly.

The Fig.2 can show slick processing. From the figure, $f0(x,y)$ is a ideal radiograph image. MTFO is the modulating transmission function of radiography imaging system, $g(x,y)$ is the radiography image, which is acquisition from imaging system. MTF1 is frequency response function of smoothing processor and as a modulate transmission function of smoothing system, $g1(x,y)$ is output which is processed by smoothing system.

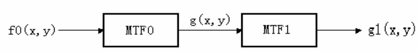


Fig.2 the Smoothing Processing effect in the system

Either frequency character of low-pass filters or modulating transmission function (MTF1) reflected the filtering performance in frequency domain. Designing filters in frequency domain can get ideal frequency characteristic, and also can get good processing effect by frequency domain processing. But frequency domain processing has a great deal of operating data. Therefore, in real-time imaging testing, usually adopt spatial domain smoothing process instead of frequency domain filtering.

Smooth processing methods in spatial domain are 2-D cross-integration procedure with proportional addition average of image and filter window arithmetic operators in spatial domain. From Fig.2 we can get that processed image is $g(x, y)$, window function is $h(x, y)$, output image is $g1(x, y)$, hence

$$g1(x, y) = g(x, y) * h(x, y) \quad (1)$$

The Fourier transformation of above equation is

$$G1(\omega_x, \omega_y) = G(\omega_x, \omega_y) \cdot H(\omega_x, \omega_y) \quad (2)$$

It is obvious that frequency response function $H(\omega_x, \omega_y)$ of window function is modulating transmission function MTF1 of slick. Suppose the window width W (is odd number commonly) of slick, proportion is 1, so the window function can be expressed as following equation:

$$h(n) = [\Lambda, 0, \underbrace{1, 1, \Lambda, 1}_{W}, 0, \Lambda] \quad (3)$$

Therefore the point N(n>w) of $h(n)$ discrete transformation can be expressed as

$$H(k) = \sum_{n=0}^{N-1} h(n) e^{-j\frac{2\pi}{N}nk} = \sum_{n=0}^{W-1} e^{-j\frac{2\pi}{N}nk}$$

$$= \frac{1 - e^{-j\frac{2\pi}{N}Wk}}{1 - e^{-j\frac{2\pi}{N}k}} = e^{-j\frac{\pi k}{N}(W-1)} \frac{\sin(\frac{\pi}{N}kW)}{\sin(\frac{\pi}{N}k)} \quad (4)$$

From equation (4) it indicates that $H(k)$ has different frequency characteristic along with different window width. According sampling theorem, the max frequency resolution is $N/2$ for a sequence with the width is N. if the image width N is decided, then the influence of smooth filtering is certain. Common slicks are rectangular window with size of 3×3,5×5,7×7, Slick is low-pass filter actually , which not only result in attenuation of high-frequency element. Meanwhile but also result in much overlay distortion in hi-frequency part of the image because of truncation of window function.As for radiography testing, whether how the width of image changing, Spatial sampling frequency has been decided by image sampling, Image resolution is up to the number of image pixel. Each pixel of the image stands for effective size of actual image, the flaw with different width has different number of pixel.Supposing ideal flaw is a crack with the width of w1 pixels, the unitary gray-level differential is 1. Fig.3 shows its crack has the form

$$g_1(n) = u(n - W1) \quad (5)$$

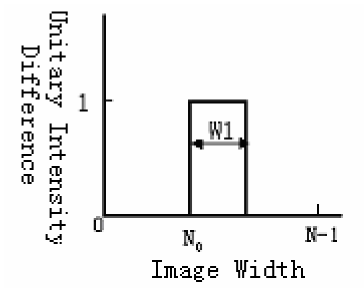


Fig.3 Ideal Crack Signal

The Discrete ourierransform of its N points is

$$|G(k)| = \left| \frac{\sin(\frac{\pi}{N}kW1)}{\sin(\frac{\pi}{N}k)} \right| \quad (6)$$

The main petal width of crack signal frequency chart can be fixed via $\sin(\frac{\pi}{N}kW1) = 0$,Namely

$$k = \frac{N}{W1} \quad (7)$$

Or unitary bandwidth is

$$B0 = \frac{1}{W1} \quad (8)$$

From (7) and (8), we can confirm the window width of slick or bandwidth of low-pass. Therefore, when choosing smoothing filter or linear low-pass processing the noise radiography image, the bandwidth of filter should be more than main petal width of least resolution flaw size. This shows, smooth filtering can decrease noise and enhance image effectively, but, if window width of smooth filter is chosen improperly. Which will induce flaw information losing of radiography image and decreasing the testing sensitivity of real-time digital radiography imaging system.. So smooth filter design must be combined with the MTF characteristic and frequency characteristic of testing object in radiography digital imaging testing, especially in application of the automatic quantitative testing.

4 Non-linear Filtering approach of radiography image

Although the linear filter can attenuate the noise of the signal average affect a lot. But also corrupt edge and lose image details at the same time. The emphasis of radiography image processing is that the flaw can be shown clearly in image, flaw (air hole,crack etc) only has the width of several pixels commonly in the whole image. In this way, the keeping edge characteristic of linear filter result to corrupt edge and lose flaw details indeed. Rank-Order filter is one kind of Non-linear filter, Rank-Order filter not only has simple arithmetic,good flexibility,can be understood and realized easily; but also has many functions, such as can smoothing image,enhancing edge,restraining noise and saving details ,so can get the most ideal combination. Following will discuss some kinds Rand-Order filter.

4.1 Median filtering

Median Filtering[1] is a slick window which include odd points. Use the median gray-level of the pixels in the window replace the gray-level of the center pixel. Supposing some pixel gray-level is f(x, y) in the image, the neighboring region of which is a rectangular window with the size of $(2k+1)\times(2l+1)$,then through Median filtering ,the gray-level of the pixel is:

$$g(x,y)=\underset{i=-k}{\overset{k}{Med_x}}\ \underset{j=-l}{\overset{l}{Med_y}}[f(x+i,y+j)] \qquad (9)$$

Hereby, Med_x and Med_y stand for the median value of horizontal direction and vertical direction respectively. The window form and size design of the Median Filtering has a great influence on the filtering effect. Different image content has different application requirement, generally adopt different window form and size. The window form of the 2-D Median Filtering has linear.,ectangular,circular, cross-shaped and ring-shaped in common use.

Generally speaking, we often adopt rectangular window or circular window for the image with long contour line object, and adopt cross-shaped window for the image with sharp-angled object.

But the window size should be less than the size of the least available object in the image. The most noticeable thing during using the 2-D Median Filtering is keeping the available filament object in image.

Median Filtering has following characteristics: the Median Filtering output has invariability for some input signal; the impulse response is zero, which decided Median Filtering has the character of eliminating impulse interference; Invariable signal response decided Median Filtering has the character of keeping edge. Therefore, adopt the Median Filtering into image processing, can restrain impulse interference and keep edge.

4.2 Contrast-Select Filtering

Contrast-Select Filtering enhances image grads in the situation of unknown noise transcendent information. Such arithmetic is a self-adaptation sequence statistic filter, which not only has simple arithmetic, but also eliminating noise at the same time of doing edge enhancement.

Such filter arithmetic will introduce as following. At the time k , the output Y_k of contrast-choice filter which with parameter J can be shown as:

$$Y_k=\begin{cases} X_k^{(N+1-J)}, & if \quad \mu_k \geq M_k \\ X_k^{(N+1+J)}, & if \quad \mu_k < M_k \end{cases} \qquad (10)$$

The window size introduced here is $2N+1$. $X_{k-N},...,X_k,...X_{k+N}$ are the sample value in the window. $X_k^{(i)}$ is sorted from small to big in the window. μ_k and M_k are sample average value and median respectively, integer J meets $1 \leq J \leq N$.

Contrast-Select Filter has the performance of enhancing the edge grads. In addition, which is not sensitive to noise. Actually ,it can cut impulse noise and some non-impulse noise, such as Gauss noise,addition white noise. Generally speaking, it'll has preferable noise attenuation feature if J is small[10].

4.3 Lower -Upper-Middle Filtering

LUM Filter[11], which is a sort of filters with good flexibility and can achieve the ideal combination of noise smoothing and keeping signal detail, both of them are opposite. And LUM also avoids a lot of defects, which is existent in multi-linear edge enhancement filter.

LUM Filter, why call it such a name, because of its output is received by lower and upper statistic of data, which has been sorted, and by comparing the filter window middle sample. LUM Filter is composed of LUM Slick and LUM Sharpener. Smoothing parameter controls smoothing character of which. The variety smoothing parameter also can adjust from non-smooth to smooth. That is to say, if the parameter is chosen as a very little smooth, then a lot of useful information will be saved and eliminate noise. Sharpening character is controlled by its parameter. In the past, edge enhancement is implemented by linear technology commonly, these linear technology include Winner filtering,High-pass filtering and non-sharpening blind age. Linear Sharpener can get good effect in most cases, however, a lot of functions can not be achieved by Linear Sharpener Such as Linear Sharpener overdoing so as to can't achieve the expectation effect. Consequently brought edge dithering or magnified background noise. But Sharpener can avoid these disadvantages. Especially, it is not sensitive to Gauss noise and eliminating impulse noise effectively. At the same time it also enhancing edge[12].

Following will discuss the arithmetic of LUM Filter. Supposing N sample-point. The center element of which is $\hat{x}$, for the 2-D signal, the rectangular sample of window, which with the size of $(2m+1)\times(2m+1)=N$ can be written as following after sorting

$$x(1) \le x(2) \le ... \le x(N) \tag{11}$$

Center sample output is $\hat{y}$.

LUM Filter, which consists of LUM Slick and LUM Sharpener. The definition of which is as follows:

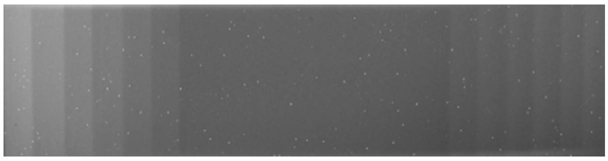
$$\hat{y}=\begin{cases} x_{(k)}, & if \quad \hat{x}<x_{(k)} \\ x_{(l)}, & if \quad x_{(l)}<\hat{x}\le t_l \\ x_{(N-l+1)}, & if \quad t_l<\hat{x}<x_{(N-l+1)} \\ x_{(N-k+1)}, & if \quad x_{(N-k+1)}<\hat{x} \\ \hat{x}, & others \end{cases} \tag{12}$$

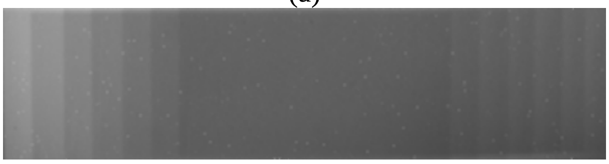
Hereby $1 \le k \le l \le (N+1)/2$.

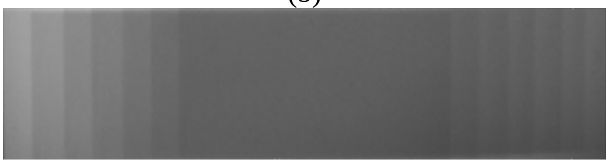
LUM Filter show different features through change the value of k and l.

5. Experimental results and Analysis

Using the system(X-Ray source voltage is 60KeV,current is 0.3mA, focus diameter is 0.5mm) as Fig.4 shows do digital imaging for some aluminum compoment.Fig.4(a) is the original image, the rest images are processed through the approach which introduced above, window size is 5×5 and window form is rectangular. (b) is the image which is processed by neighboring average filtering; (c) ,(d) ,(e) are the images which are processed by median filtering. the window form are rectangular,cross-shaped,rows and cols respectively;(f) is contrast-select filtering, window form of which is rectangular;(g) ,(h) ,(i)are the images processed by LUM filtering, window form of which are rectangular,cross-shaped,rows and cols respectively. From the processed results shows that: neighboring average filtering corrupting edge at the same time of eliminating image noise, and this kind of filter has no good effect for impulse noise; Median Filtering keep the edge information at the same time of eliminating image impulse noise, the effect of range separable median filtering is better than above approach for this experimental image. Contrast-Select filtering enhancing the edge at the same time of eliminating the noise; LUM filter which is a very flexible filter, as long as select adequate smoothing parameter k and sharpening parameter l, LUM filter made noise smoothing ,keeping and enhancing edge information these two conflicts into a ideal combination. This paper selected $k=3$ $l=3$, for this image, the effect of range separable LUM Filtering is the best.


(a)


(b)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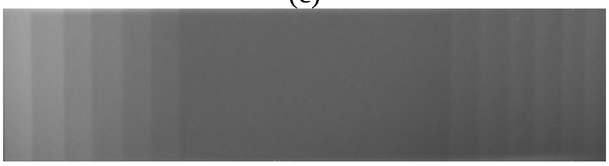
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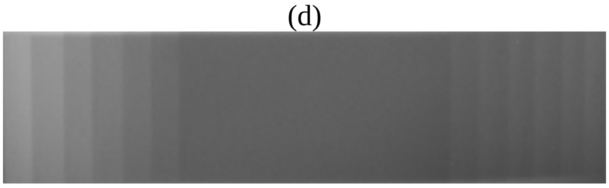
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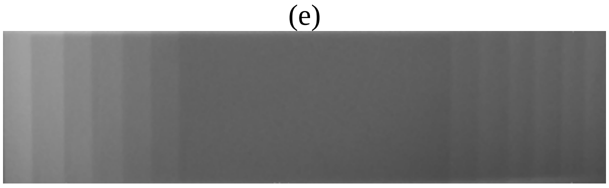
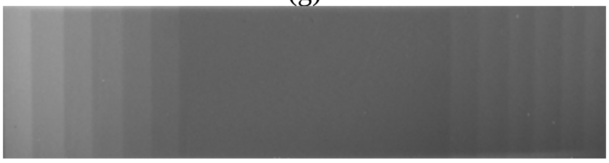
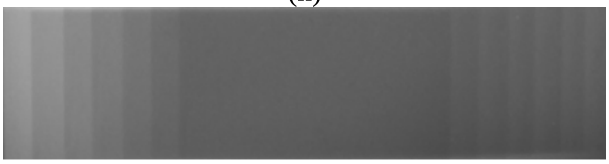

(f)


(g)

(h)

(i)
Fig.4 Original and Processed Image

6. Conclusion

In the system of radiography digital imaging, because the influence of the quanta noise, quantitive noise ,dispersion noise,system heat noise etc, resulted in what output image submerged into noise, much important detail and edge can't be distinguished clearly. Linear Filtering corrupted edge at the same time of smoothing image noise. Order Filtering kept and enhanced detail at the same time of decreasing image noise. In the test system of industry radiography digital imaging system. Because of the component's flaw (e.g. crack,air hole) has little edge information, so order filtering can get good effect for radiography image processing.

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