Image enhancement algorithm based on Retinex for Small-bore steel tube butt weld's X-ray imaging

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Abstract: - It is very common to use X-ray digital detection for the Small-bore steel tube butt weld. But the X-ray images have some shortcomings such as that contrast is not high, background noise is big, and the details can not be shown obviously, these shortcomings take a great inconvenience for the small-bore steel tube butt weld testing. So the detection efficiency can not be increased. Based on this, the Retinex algorithm is discussed and analyzed, such as single-scale of Retinex, multi-scale of Retinex, alterable framework of Retinex. Then it is applied to use an enhancement algorithm of improved Alterable framework on Retinex, and use this enhancement algorithm for X-ray image. This enhancement algorithm do not ask for much contrast of original image, which can effectively improve the original image contrast and image quality, the details of the image achieve the best visual effects. After the theoretical analysis and experimental results, we can see that, this enhancement algorithm can effectively enhance the image contrast, inhibit the background noise, compared with homomorphic filtering and histogram equalization algorithm. The standard of the image which is processed by this method can achieve the higher testing standard compared with homomorphic filtering and histogram equalization algorithm.

Key-words: - radiographic image; image enhancement; Retinex algorithm, single-scale Retinex algorithm， Multi-scale Retinex algorithm， alterable framework model, butt weld

1. Introduction

X-ray imaging system has been widely applied in industrial non-destructive testing. In the boiler pipe butt weld detection, it has a wide range of applications. Ray imaging has a direct impact on the efficiency and quality of the weld detection. In the X-ray imaging systems, because of the contrast of radiography, the non-definition of radiography, and a variety of constraints of hardware, its image is existed characteristics such as big noise, low contrast, image blurring, image detail information has been submerged by the noise, the image quality difficult to achieve the required industry standards. Effective image enhancement algorithm can filter out system noise and background noise, enhance the image contrast, and the details of the workpiece will be separated from the background, so that clear display of the details.

There are so many X-ray image enhancement algorithm now, but these methods have good results only for some special images, for example, histogram equalization have good results when the original image with low gray-scale, but when the image with high gray scale that show many details, this enhance method can not be satisfactory results; when the image has a greater difference in brightness, homomorphic filter will engender more feint. Actually, X-ray image have very low brightness and many background noise, it can not distinguish the information of image detail in the dark region whit conventional enhancement methods, so it need an effective image enhancement algorithm, not only to enhance the image details of information in the dark region, but also to suppress the system noise and background noise, in order to better display the image.

To this end, this paper contraposes the characteristics of X-ray images and the inadequacy of conventional enhancement methods propose variable framework model of Retinex algorithm for the X-ray image enhancement, it is to meet the needs of industrial X-ray inspection standards to improve the detection efficiency and quality.

2. Retinex Theory

Color is important information source to describe, distinguish and identify an object for human and other biological visual system. In the image, the object can be displayed in different color saturation and has nothing to do with the change of the light. The human's visual perception is more sensitive to the reflection light of the object's surface. To this end, Retinex theory is introduced by Land to explain human's visual model, and establish illumination invariance model of which the color has nothing to do with. The basic objective of Retinex model is carry out image reconstruction, making the image after reconstruction the same as the observer saw the images at the scene.

Retinex model is based on reflection imaging illumination model ,it is very similar to homomorphic filtering: irradiation light is more smooth than the changes of reflected light, you can use low-pass filter to estimate the fuzzy computing on the input image; reflected light is divided from the input image and smooth images.

Retinex ("Retina" and "Cortex" abbreviate) is proposed by Edwin Land is different from the traditional image enhancement algorithm, such as linear, nonlinear transform, image sharpening and so on, that can only enhance particular type of characteristics of the image, such as compress the dynamic range of images, or image edge enhancement, etc., Retinex balance three aspects in compress the dynamic range of gray-scale, edge enhancement and color constancy, which can be use with different types of images and self-adaptive enhance.

Retinex basic principles are to be divided into an brightness image and reflection image, then enhance images to achieve the purpose by reducing the impact of image brightness on reflection image According to Land's Retinex model, an image can be defined as $S(x, y)$, is shown as fig1:

$$S(x,y)=R(x,y)\times L(x,y) \quad \text{………(1)}$$

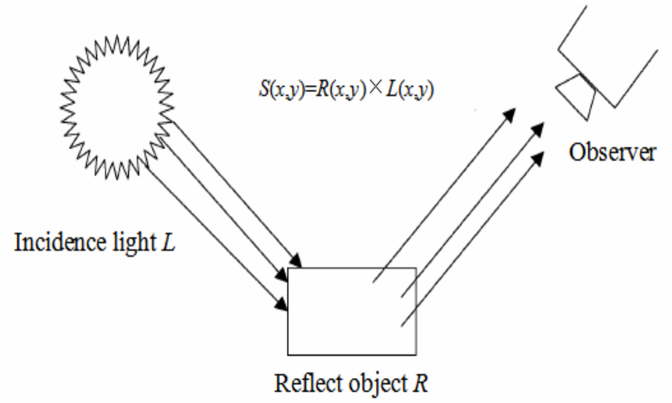

Fig1 Schematic diagram of Retinex

R express the brightness of the surrounding environment, has nothing to do with the objects, and L is the reflectivity of objects, has nothing to do with the lighting, which includes details of the characteristics of objects.

The algorithm process of Retinex of is shown as Figure 2:

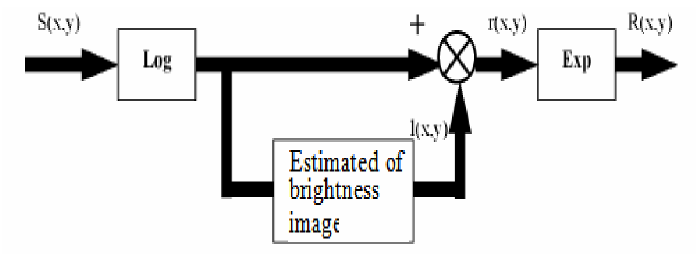

Fig 2 The algorithm process of Retinex

The key of the Retinex theory with image enhancement is calculated the brightness image from the original images effectually, but calculated brightness image from the original image is a non-problem in math, it can only be estimated through mathematical approximation to estimate image brightness.

In the process of development of Retinex theory, according to the different methods of image brightness estimates.

There is a number of image enhancement methods based on the Retinex theory, such as the random walk algorithm, Poisson's equation algorithm, homomorphic filtering algorithm, single-scale Retinex algorithm, multi-scale Retinex algorithm, McCann's Retinex algorithm, the latest variable Retinex model, etc.

2.1 single-scale Retinex algorithm

Single-scale Retinex algorithm is the improvements and realized for Center / Surround Retinex (Center Surround Retinex) in 1997 by Jobson and his colleagues. *I (x, y)* for the original image, *L (x, y)* for the brightness function, R (x, y) for the reflectance images, single-scale Retinex can be expressed as formula 2:

$$\log R(x,y) = \frac{\log I(x,y)}{\log L(x,y)} = \log I(x,y) - \log[F(x,y) * I(x,y)]$$

………(2)

F (x, y) is the low-pass convolution function, which is estimated brightness image *L (x, y)* from the original image.

According to the visual theory, because of the existence of lamp-house brightness and objects' reflect at the scene, which correspond to the brightness image and reflection image. That is the reason why human eyes can see the objects. Which color of light can be reflected is decided by the nature of the object itself, not changes because of the light source or light brightness.

Thus 4.9 show that, removal the impact of brightness image in the original brightness, the nature of light reflection color can be gained, which is color constancy

At the same time, the human eye is more sensitive for the gray edge, such as high-frequency information that, due to the convolution function in 4.9 is a low-pass function, so *F (x, y)* is estimated the brightness of the image *L (x, y)* correspond to low-frequency part of the original images. Low-frequency part *L (x, y)* of the image is removed from the original ,which is single-scale Retinex, received original description of high-frequency part, that corresponds to the edge of the image. Therefore, not only color constancy can be achieved, and edge enhancement can be achieved by the single-scale Retinex

According to optical theory, assuming that *Q (x, y)* is the source brightness distribution of the air space, *W (x, y)* is the reflection light's distribution of scene objects. The distribution of the light reflection in the eyes can be described as 3:

$$R(x,y) = \log \frac{Q(x,y) \bullet W(x,y)}{\overline{Q(x,y)} \bullet \overline{W(x,y)}}$$

……… (3)

$\overline{Q(x,y)} \bullet \overline{W(x,y)}$ is the product of light source in space distribution and the distribution average of reflection light multiplied, describing the brightness of objects in the eyes. Brightness light source is usually the same, that is, formula 4

$$Q(x,y) \approx \overline{Q(x,y)}$$

……… (4)

So takes formula 4 into the formula 3, formula5 can be here:

$$R(x,y) = \log \frac{W(x,y)}{\overline{W(x,y)}}$$

……… (5)

It also describes the reflection image *R (x, y)* is only determined by the reflection light's distribution and the average of reflection light's distribution, nothing to do with the source brightness.

Therefore, if the brightness image can be calculated from the original image, it can be gained the mathematical description of the reflection image *R (x, y)*, and thus to achieve color constancy, dynamic range compression and edge enhancement.

However, calculated the brightness image from the original image in mathematics is a very complex issue. In a single-scale Retinex image enhancement algorithm, Johnson demonstrated that the Gaussian deconvolution function can provide more to deal with the original image, and can better enhance the image, which is expressed as formula 6

$$F(x,y) = \lambda \cdot e^{\frac{-(x^2+y^2)}{c^2}}$$

……… ……… (6)

Here, *C* is the scale constant, C smaller, gray-scale dynamic range compression more, C greater, the more powerful image sharpening. Experiments show that, when the scale constant between 80-100, that the gray-scale dynamic range compression and contrast enhancement can achieve a better balance. λ is the constant matrix, it can be formula 7:

$$\iint F(x,y)dxdy = 1$$

………………………(7)

2.2 Multi-scale Retinex algorithm

Multi Scale Retinex (MSR) algorithm is an image enhancement method, not only compress image dynamic range very good, but also guarantee images' color constancy. The algorithm can be described by formula 8:

$$R(x,y) = \sum_{k=1}^{M} W_k (\log I_i(x,y) - \log[F_k(x,y) * I_i(x,y)]), i = 1, \Lambda\ , N$$

………(8)

The first subscript i is said i spectral band, N is for the number of spectral bands, N = 1 represent of gray image, N = 3 represent of color images. W_k represent the weight coefficient associated F_k, M represent the number of environment functions. Environment function can be expressed as formula9:

$$F(x,y) = K \bullet \exp(-(x^2+y^2)/c^2)$$

……… (9)

C is the scaling function, *K* satisfy the following formula 10:

$$\iint F(x,y)dxdy = 1$$

……………… (10)

F, K is selected different standard deviation C_k, it is used to control the scope of the environment function scale. The weight of each scale take 1 / 3 of the same value. * represent of convolution, the effect of MSR algorithm is deal with the environment surround function scaling factor *C*, *C* determines the scope of the role of convolution nuclear, *C* greater, the greater of the scope of convolution nuclear, taking into greater account of around impact when calculate a pixel, then the overall effect of image processing is better, contrarily, the local characteristics is distinctness.

The algorithm makes the output image *R* dark, it can not achieve the best visual effects, in order to get better results, it take the processing similar to histogram interception for the output image, the final output is formula11:

$$R(x,y) = G(\sum_{k=1}^{M} W_k (\log I_i(x,y) - \log[F_k(x,y) * I_i(x,y)])) + b \quad , i = 1, \Lambda\ , N$$

………(11)

G and b are constants of the gain and offset, determining their value after the experiment. The choice of parameters shows a greater impact for the quality of the final image. Parameter mainly depends on manual adjustment in this algorithm.

3. Alterable framework model based on Retinex theory

Alterable framework model set up the assumptions which based on the Retinex algorithm. These assumptions include:

1）Incident light R has the characteristics of spatial smoothing.

2）Since R is limited to [0, 1] and is monotonous on log-domain, so the image of incident brightness component has: S≥ R.

3）Incidence component L should be as close as possible to the output brightness of the image.

4）Incident light in the image borders should have smoothness similar constant.

Based on these assumptions above on, Kimmel and others give the following equation:

$$F[L]=\int_{\Omega}((|\nabla L|)^2+\alpha(L-S)^2+\beta|\nabla(L-S)|^2)dxdy$$

Subject to: $L\geq S, and <\nabla L, \vec{n}>=o \; on \partial\Omega$

…………(12)

In the type above on, Ω is image, L is the brightness image, S is original image, $\partial\Omega$ express image edge, α and β are non-negative coefficient. $|\nabla L|$ of the above formula makes the image brightness spatial smoothing. The condition $(L-S)^2$ made the brightness image near the original image; the difference between these is the reflection images. $|\nabla(L-S|^2$ is similar to Bayesian expressions, so that the reflection images have been better suited to visual characteristics.

If we can find the numerical solution of this equation, we will receive the brightness image L , and then realized image enhancement with Retinex algorithm.

4. Image enhancement algorithms for X-ray Image base on an improved Alterable framework on Retinex

Although the above model can correctly solve the Retinex problem, but it has several shortcomings:

(1) Halo

Halo's are often existed in Retinex algorithm. It is a direct result of smooth assumptions as described above. Light traversing from bright areas to dark region, the smoothness require it maintain a relatively high value near the edge of the dark region, and then smoothly reduced to the brightness value of dark region. Thus, when the region near the edge of the darkness was removed, the effects associated with Halo.

(2) Noise

In the Image of darkness regional Retinex algorithm will try for a contrast it is very similar to the effect with standard Gamma correction. The try for cause the noise amplification, and performan significantly on low-quality images or no compression image.

(3) Iterative Solution:

The above model naturally lead to an iterative solution required.

In view of the deficiencies above the alterable framework of the Retinex, the new assumptions used to improve the variable framework of the Retinex to solve the halo and noise problem, and gains a new iterative formula.

4.1 The realization of improved alterable framework of the Retinex algorithm

Based on the analysis above, the model required some modifications. Analyses the equation of variable framework model

(1) The first restriction $|\nabla L|^2$ of the equation is in order to impel the incidence heft as spatial smooth as possible.

(2) In the variable framework of the model, the third restriction $|\nabla(L-S)|$ is in order to R as smooth as possible,. The strength of the restriction is decided by the free parameter β.

(3) The second restriction conditions $L \geq S$ is in order to make L as close as S, which means that R should be small as possible. However, in order to not make L excessively near S, α should be small as possible.

After taking into account the effect of image enhancement, here should be

1) $\beta = 0$. Since the emergence of halo effect, the main reason for this is that R is too sleek and crossed the borders of objects, so we put it here come up to 0 , this can effectively remove the halo effect.

2) $\alpha \to 0$ is a reasonable assumption, because α should be as small as possible

Under the new assumptions, gained the new equations:

$$\begin{cases} \forall(x,y) \in \Omega \\ \dfrac{\partial F[L]}{\partial L} = 0 = -\Delta L + \alpha(L-S) \approx -\Delta L \\ L > S \end{cases} \qquad \text{………..(13)}$$

It is used the method of steepest gradient descent to solve the equation. Iterative equation as follows:

$$L_S = L_{S-1} - \mu_{PNSD} \bullet G \qquad \text{………………………(14)}$$

L_s and L_{s-1} are brightness image in step j and step $j-1$ respectively. G is the gradient images of $F(L)$.

$$G = -\Delta L_{S-1} \qquad \text{………………………(15)}$$

$$\mu_{PNSD} = \frac{\int |G|^2}{\int \nabla |G|^2} \qquad \text{…………………………(16)}$$

Define the inner product for:

$$\langle G, F \rangle = \sum_{n=1}^{n} \sum_{m=1}^{m} G(n,m) \bullet F(n,m) \qquad \text{………..(17)}$$

K_{LAP} is Laplace sharpening factor, therefore:

$$\int_\Omega |\nabla G|^2 = \int_\Omega G\nabla G - G \approx \langle G, \Delta G \rangle \qquad \text{…………..(18)}$$

$$G \approx -\Delta l_{s-1} \approx L_{s-1} * K_{LAP} \approx - L_{s-1} * K_{LAP} * K_{LAP} \approx -\Delta G \qquad \text{………………(19)}$$

Results can be obtained from the above:

$$\int_\Omega |G|^2 \approx \langle G, G \rangle \approx -\langle G, \Delta G \rangle \approx \int_\Omega |\nabla G|^2 \qquad \text{……..(20)}$$

$$\mu_{PNSD} = \frac{\int |G|^2}{\int (\alpha |G|^2 + \nabla |G|^2)} \approx 1 \qquad \text{………………(21)}$$

Thus can gain the concluded that if $\alpha \to 0$, $\beta = 0$, it will have $\mu = 1$

Therefore, the iterative formula can simplify as follows:

$$L_S = L_{S-1} - G \qquad \text{…………………………(22)}$$

This new iterative formula is not only easier, but also effective keep within limits of halo phenomena and noise than the original formula. After some iteration, the brightness of images L can be obtained for one of the best approximation value, and then from the original image S are product of brightness image and reflection images, therefore, so obtain the reflection images used the original image minus the brightness image by logarithm domain, and thus in line with the image enhancements characteristics of human visual.

4.2 Result and analyses

The experiment using the quality standards No. ASTM11 of the United States which is commonly using in ray detection, the workpieces are boiler pipe's butt weld for 4.5mm wall thickness, using double-wall impact of industrial X-ray irradiation method in the experiment.

1. Original image

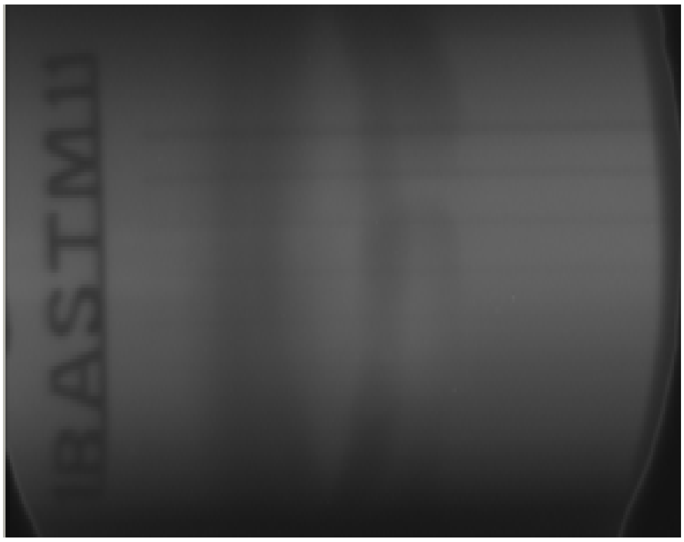

Fig1(a) Original image

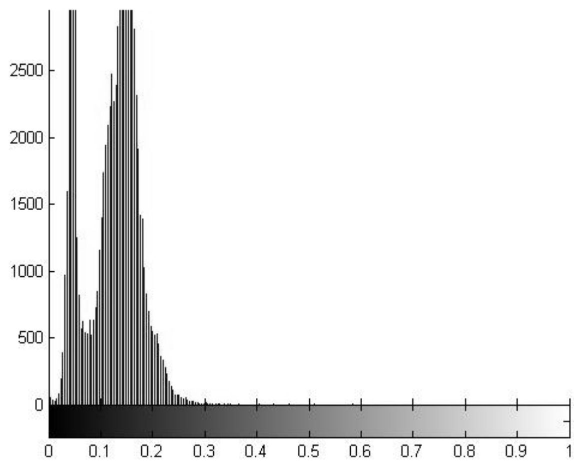

Fig1(b) Original image's Histogram

2. Histogram equalization image

Fig2(a) Histogram equalization

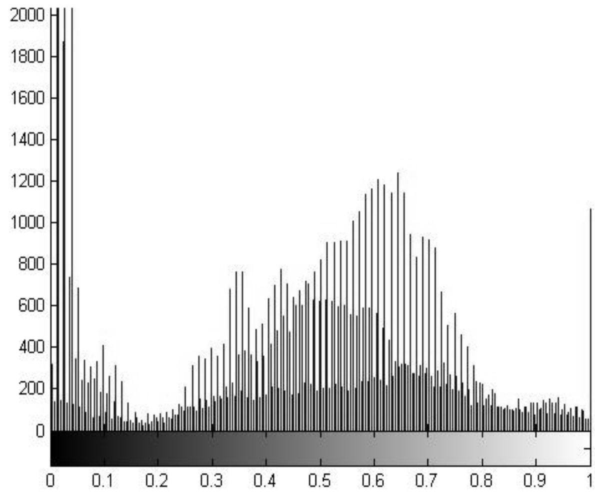

Fig2(b) Histogram equalization's Histogram

2. Homomorphic filtering

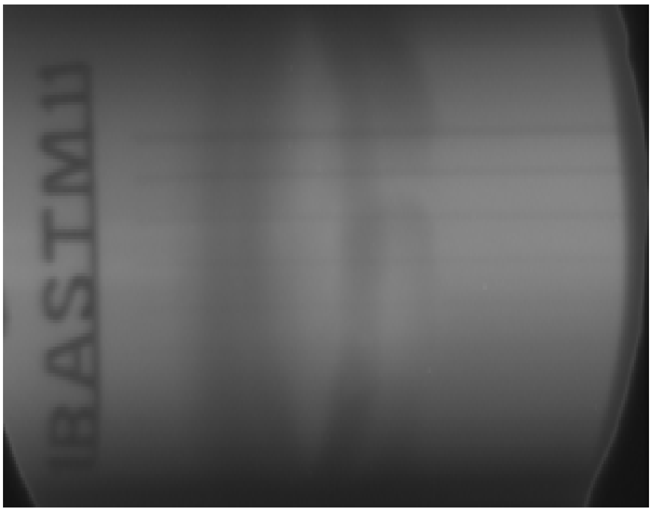

Fig3(a) Homomorphic filtering

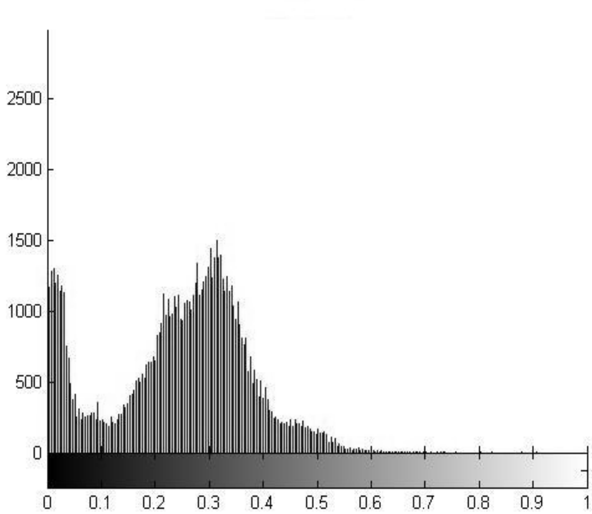

Fig3(b) Homomorphic filtering's histogram

4. Improved variable framework of the Retinex algorithm

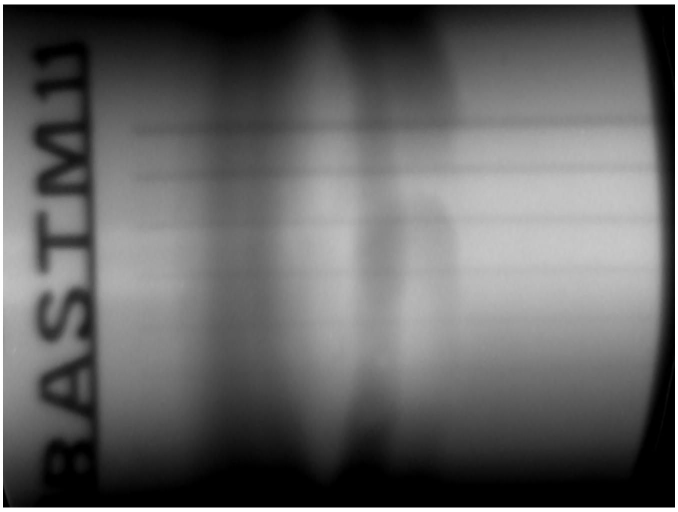

Fig4（a） Improved variable framework of the Retinex algorithm

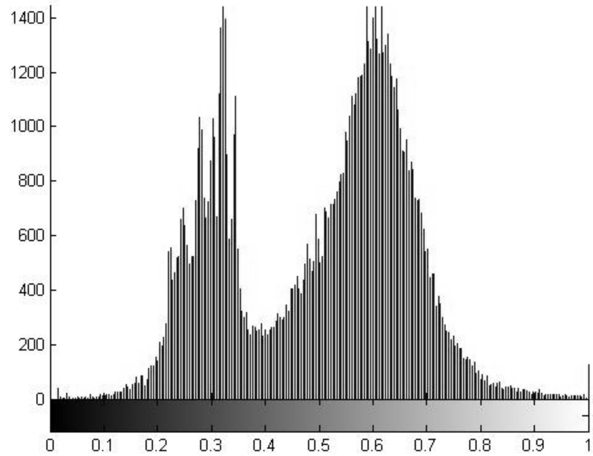

Fig4 (b) Improved variable framework of the Retinex algorithm's histogram

From the figures above, we can see only the third of the image quality meter in the original image, and clearly visible the fifth by deal with improved alterable framework of the Retinex algorithm , meet and exceed the standards of the United States.

We can find the comparison that in the circumstances of original image with the information it is difficult to distinguish: histogram equalization algorithm to improve the overall brightness simultaneously, but images edge become blurred and led to a decline in display some details.

Homomorphic filtering improve contrast significantly, but this image enhancement method is still not ideal for the dark zone, the image gray-scale is concentrated in the dark zone, the overall effect is dark.

Improved variable framework model of Retinex algorithm can be relatively satisfied with the enhanced result, image contrast has been dramatically enhanced, and restrain the noise. Because of this algorithm do not ask for much of the original image contrast, it can effectively enhance the image information in dark areas, so that it can make the image more clearly.

The experimental results prove that this algorithm not only enhances the image contrast, but also restrains the background noise, while making detail of the workpiece more obvious, and the scope of application is wider.

5. Conclusion

X-ray image's contrast is low, background noise is obvious, and it is not easy to show the details of the measured workpiece. This article aims at characteristics of X-ray image, using improved variable framework of Retinex algorithm. Experimental results show that the algorithm deals with image's gray-scale with better results, and improves the image contrast, restrains noise at the same time, so that it clearly display the details of X-ray imaging.

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