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Optimizing Technology Research of Imaging Quality on X-ray Digital Imaging

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Abstract: It has become an inevitable development that X-ray digital imaging detectors replace film-screen. The imaging quality of X-ray digital detector could not reach the level of film-screen due to its unique characteristics. It is the key that to research the method of improving and optimizing the digital imaging quality. The main factors to impact X-ray digital imaging quality is inherent non-uniformity of detector and random noise of the system. By analyzing imaging characteristics and mechanism of digital detector the non-uniformity correction model is established. The high imaging quality obtained is equal to B level of film-screen for contrast sensitivity in the condition of optimizing physical and penetrating parameters of X-ray digital imaging system with noise suppression technology. The optimization technology validated by experiment is feasibility and universal, can be applied to all types of X-ray digital testing systems.

Keywords: X-ray, digital image, imaging quality, non-uniformity, noise

1、Introduction

The development of X-ray digital imaging technology benefits from which the digital imaging detector is successfully developed as its core components, with digital imaging devices entering into industrial nondestructive testing market, it is certain that X-ray digitization detection technology replaces the film photography with X-ray testing development.

Through the use of computers digital image processing technologies, X-ray digital imaging technology reduces the image noise, greatly improves the image contrast and clarity, the imaging quality can compare favorably with X-ray film quality. Digital imaging quality can achieve B-level of the film photography, and reduce the residual rate, at the same time reduce ray dose, and improve the efficiency of testing[1]. Digital imaging system also has great tolerance, it can realize once imaging for the workpiece of large thickness range.

The digital detector inherent characteristics makes noise factors of impacting on the imaging quality which is not only the random noise ,but also the inherent noise detector during the actual testing imaging process, so the X-ray digital imaging optimization of high image quality instead of film photography is not only imaging system's technological conditions, but also the random noise suppression and the detector inherent noise's elimination will be the key.

2、The analysis of noise factor

The output image of the digital detector is mainly influenced by the three kinds of noise: Photon noise σ_Q, Electron noise σ_E and Nonuniformity σ_{NU} .

The total noise is: $\sigma_T = \sqrt{\sigma_Q^2 + \sigma_E^2 + \sigma_{NU}^2}$

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2.1 Photon noise

Photon noise dependents on the pixel point absorbing the photon number in the entire exposure time, it is caused by the X-ray photon statistical distribution. Photon noise is the main source noise of digital detectors which is subject to Poisson distribution in the photon detector, the standard deviation of distribution is proportional to its Means Square root, and more than electronic noise[3].

For the multi-storey detectors structure, the signal of each pixel is:

$$s = \sum_i k_i n_i \text{ , and } \quad \sigma_Q \propto \sqrt{s}$$

Where： n_i is the photon number of each pixel absorption for the I layer of; k_i is the signal of each photon for the i layer.

2.2 Electron noise

Electron noise is mainly composed of three kinds of noise[2]: ADC noise σ_{ADC}, row noise σ_L, pixel noise σ_p, so the total Electron noise is:

$$\sigma_E = \sqrt{\sigma_{ADC}^2 + \sigma_L^2 + \sigma_p^2}$$

Where： $\sigma_L = \sqrt{\sigma_J^2 + \sigma_A^2}$; $\sigma_p = \sqrt{\sigma_{kTC}^2 + \sigma_T^2 + \sigma_S^2}$

σ_J is Johnson noise, it comes from the resistance and capacitance of the data lines;

σ_A is charge amplifiers noise, it comes from the design of charge amplifiers and the capacitance of the data lines;

σ_{kTC} is switching noise, it comes from pixel capacitance;

σ_T is trap noise, it comes from the length and width of TFT and the trap density of amorphous silicon;

σ_S is dispersing grain noise, it is determined by the leakage current and the frame cycle.

Such noise has been suppressed in the circuit design and development process, the impact is very small, so this paper does not consider.

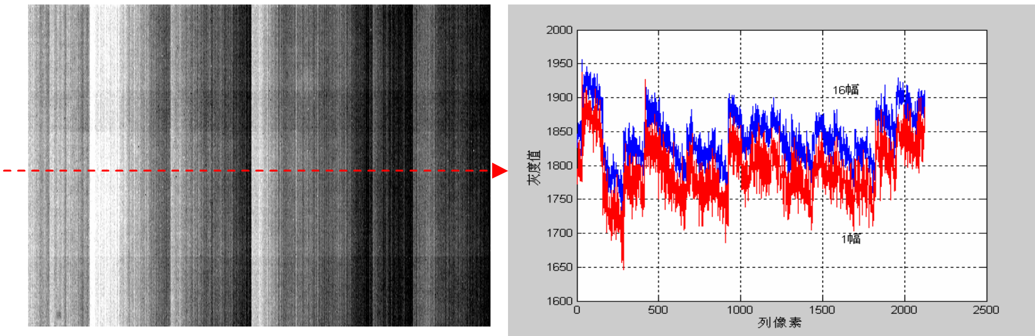
2.3 Nonuniformity

The nonuniformity is mainly the detector inherent structure noise, including the nonuniformities of the scintillator material properties and pixel response and A / D converter and the amplifier response. The nonuniformity is the most important source of noise of affecting image quality.

Figure 1 is the noise image of X-ray testing system without the workpiece basing on digital detector. The noise influence of the image performs for the non-uniformity of each pixel brightness, it will not only affect the human eye visibility but also the resolution of the defect, while directly relate to the imaging signal to noise ratio (SNR). So how to control and eliminate the noise, raise image quality of the digital detector imaging is the primary problem of ray detection.

3、the correction technology of inherent noise

We know that random noise and inherent noise are main factors affecting imaging quality of systems in front of the analysis, the testing analysis of both noises affecting the extent as shown in Figure 1.



1frame：σ= 42； 16frames：σ=38

The gray curve of Figure 1 shows that the standard deviation of the image has a small decline after the 16 image are stacked, that is, system noise suppression is not obvious at this time, the nonuniformity of the system is more than random noise for the impacting of the system image quality. So it is the primary problem that eliminates inconsistencies for the optimization of system image quality.

Because the nonuniformity is the inherent characteristics of the pixel, so it could theoretically be corrected. We regard X-ray digital imaging system as a linear system; baseline images come from the detector itself within the line range are used to correct the actual testing image[4].

（1）Acquiring of baseline images:

We acquire a dark field image (no-ray images) $B(x_i, y_i)$ and a light field image (X-ray image) $G(x_i, y_i)$ in the absence of any part. The arbitrary image correction factor K will be got in accordance with the formula (1) .

$$K(x_i, y_i) = \frac{\overline{G(x_i, y_i) - B(x_i, y_i)}}{G(x_i, y_i) - B(x_i, y_i)} \qquad (1)$$

The original image $I_0(x, y)$ of system acquisition including the part can get the corrected image of the nonuniformity in accordance with the formula (2):

$$I_g(x_i, y_i) = K(x_i, y_i) \times \frac{I_0(x_i, y_i) - B(x_i, y_i)}{G(x_i, y_i) - B(x_i, y_i)} \qquad (2)$$

Figure 2 shows a correction image for figure 1. It can be seen from the figure: the image standard deviation decline from 18 to 5 after the nonuniformity corrected, that is, the image quality is improved significantly by reduction noise, at this time the residual noise is only random noise.

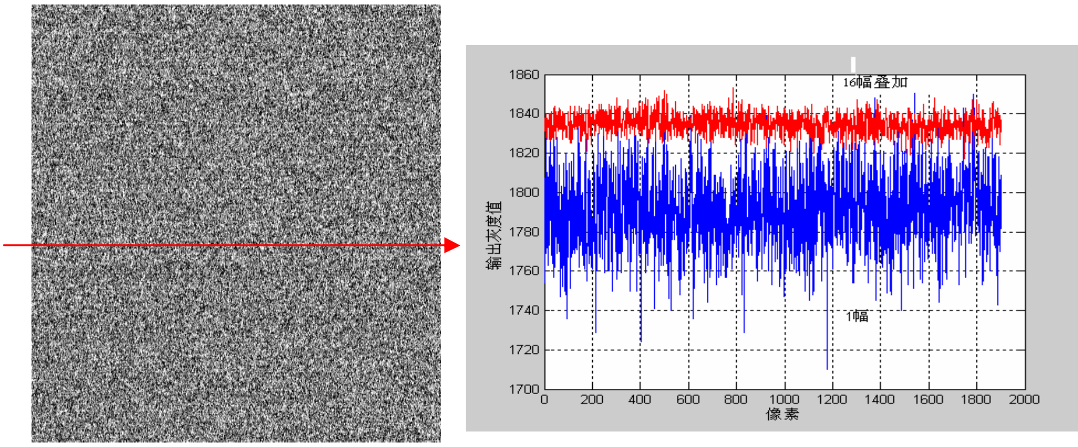
3、the reduction technology of random noise

Because of the characteristics of random noise, currently the most effective random noise suppression technology is extending exposure time to improve the exposure or a number of image superimposed for digital still imaging (non-real-time imaging).

(1) the relationship between the exposure and the SNR

The exposure of imaging is decided by the exposure time and the used current. The exposure time is the acquisition frame rate of the detector in digital imaging, the general detectors have fixed or the optional collecting frame rate.

Table 1 gives SNR relation of different frame rate for detector at a fixed voltage and the current circumstances. Figure 3 gives the relationship between the exposure and the output signal.



1frame：σ= 18.7436； 16frames：σ=5.3141

Table 1 the statistical quantity compare of images with different frame frequency

100kV，1mA	mean	Standard deviation	SNR
1f/s	759.3409	7.7434	98.0628
2f/s	379.4243	5.5348	68.5529
3f/s	252.9287	4.6249	54.6884

It can be seen from the chart: Simply increasing exposure will increase image noise in other conditions remain unchanged. But because the signal output also increases, and the level of increasing is greater than the rate of noise, so increasing exposure can increase SNR of the output imaging, that is, the increasing exposure will improve SNR of the system.

From Figure 3 can also be seen: 1f/s as a benchmark, with the current increase, 2f/s output value is its 1 / 2, 3 f/s output value is its 1 / 3. Based on this law, we can get experimental statistics of table 2. Experimental conditions are as follows: voltage of 100 kV, the current:1 f/s: 1.0mA; 2f/s: 2.0mA; 3f/s: 3.0mA got the relationship between the stacks and the standard deviation,

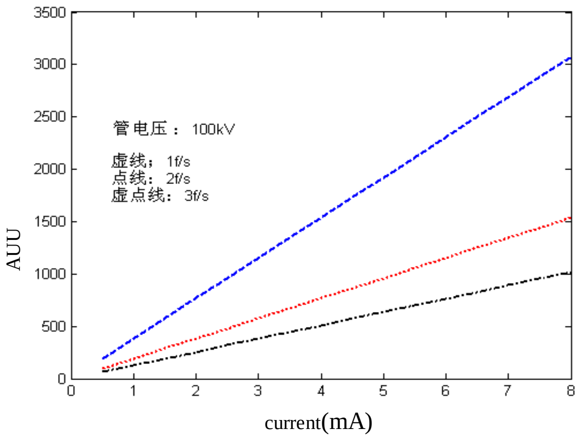


Fig 3 the relation between different frame frequency and tube current

Table2 the statistical quantity of different frame frequency under the tube current

	N	1	2	4	8	16	32	64	128	256
σ	1f/s	7.8798	5.9878	4.4790	3.3085	2.4617	1.8756	1.4842	1.2380	1.0929
	2f/s	7.8802	5.9891	4.4815	3.3114	2.4639	1.8760	1.4884	1.2439	1.0942
	3f/s	7.7935	5.9390	4.4501	3.2958	2.4536	1.8701	1.4792	1.2339	1.0879

（2）the relationship between Stacks and the SNR

For the random noise subject to the Poisson distribution, if N images are stacked and average, then the image SNR can improve $\sqrt{N}$ times. Several stacks is collecting multiple images in a certain period of time, a pixel point-to-point stack average is used to suppress noise according to the random noise characteristics. The experimental conditions of Table 3 and Figure 4 were as follows: Working frame rate is 2f/s, filter plate selects 0.75 mm brass, Ray input conditions are as follows: voltage of 100 kV, the current 2.2 mA, the relationship of the corrected images is performing a number of stacks, imaging standard deviation and SNR (calculated from imaging pixel size of 400 × 400).

Table 3 the relation between superposition frames and output statistical quantity

N	1	2	4	6	8	16	32	48	64	128	256
mean	729.	725.	730.	732.	733.	731.	733	734.	733.	734.	734.
σ	7.59	5.79	4.27	3.66	3.23	2.41	1.84	1.59	1.46	1.198	1.04
SNR	96.02	125	166	199	226	302	397	459	501.	612.	702.

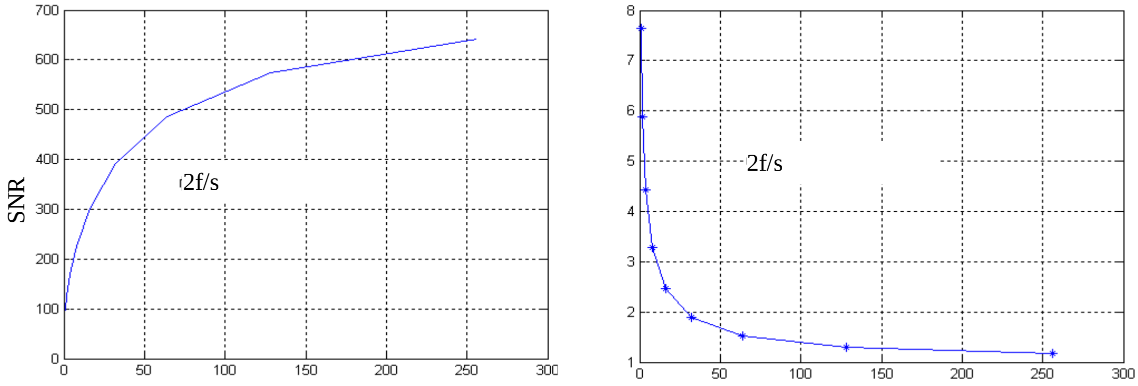
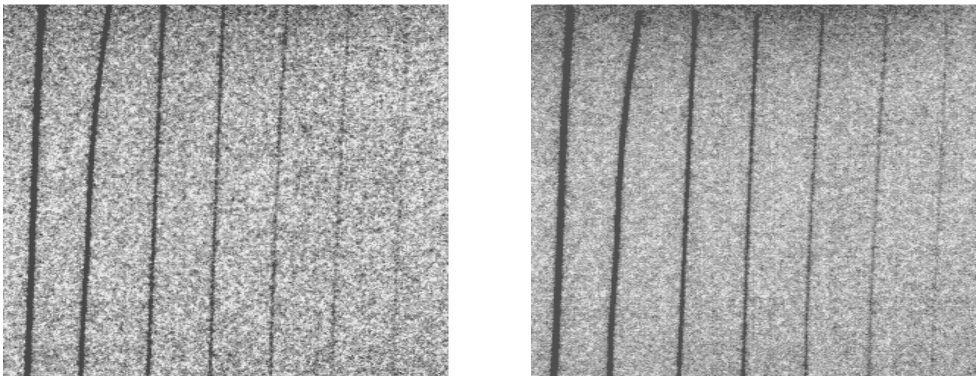


Fig 4 the relation between superposition frames and output statistical quantity

The results showed that a number of stacks can effectively suppress the noise. With the increase of superposition, the standard deviation decreased gradually, when the rate of superposition N ≥ 64, the lower rate of the standard deviation decreased, this show that the random noise has been relatively small at this time. Therefore, the best superposition N chooses 64 or 128. Figure 5 is the imaging results of different superimposition.



5、conclusion

Noise suppression is the key to improve SNR and image quality. For X-ray digital imaging, these two measures must be taken: First, suppression of random noise; the second, the correction of the detector inherent noise - nonuniformity.

(1) For the random noise: A number of stacks are the most effective way of random noise suppression, but for dynamic imaging, superimposition means has limited imaging speed, at this time, it need use intra-smoothing technology or frame superimposed technology for processing.

(2) For the inherent noise: As long as the imaging system belong to within the linear range, the above correction methods are effective for any digital detectors. When the system beyond the linear imaging range, it need propose corresponding to the non-linear correction methods for actual system features.

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