

Design principles of a novel X-ray imaging system

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A novel X-ray imaging system (NXRIS) and the design principles are given in this paper. Different from the existing digital X-ray imaging systems, the X-ray image intensifying system of NXRIS is a non-vacuum system composed of the intensifying screen and the brightness intensifier, and the brightness intensifier is named low light level image intensifier applied in military affairs. This structure makes NXRIS of big visual field (15 inch, even to larger) and low cost. When designing NXRIS, the spectral compatibility of the component devices and the relation between the visual field and the spatial resolution of the component devices are analyzed. The images produced by NXRIS are given and the image performance is good enough to be applied to security checking, non-destructive testing, and industry detection.

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Since X-ray was applied to medical imaging, the imaging techniques have experienced several improvements^[1,2]. However each X-ray imaging technique has its own shortcomings. For example, screen-film cannot give real-time images, X-ray image intensifier is usually imported, the image performance of computed radiography (CR) is worse than that of the screen-film system, and the direct digital radiography (DDR) is very advanced but very expensive.

To get a digital X-ray imaging system of big visual field and low cost, the novel X-ray imaging system (NXRIS) is designed and it is mainly composed of the intensifying device and the image output device. Its schematic diagram is shown in Fig. 1. The X-ray intensifying device is the X-ray intensifying screen lens coupled to the brightness intensifier, which converts the X-ray photon into many light photons. The image output device, which makes the final image with better quality, is composed of charge-coupled device (CCD), digital image processor and display.

Although the X-ray intensifying screen amplifies X-ray photon, the brightness is still not enough to produce a clear image. Therefore, the brightness intensifier is joined between the intensifying screen and CCD to increase the brightness millions times further.

Undoubtedly, the spectral compatibility^[3] of the intensifying screen and the brightness intensifier is important to the imaging performance of NXRIS, and the spectral matching factor α which can define the degree of two devices' spectral compatibility is given in

$$\alpha = \frac{\int_0^{\infty} P(\lambda)R(\lambda)d\lambda}{\int_0^{\infty} P(\lambda)d\lambda}, \tag{1}$$

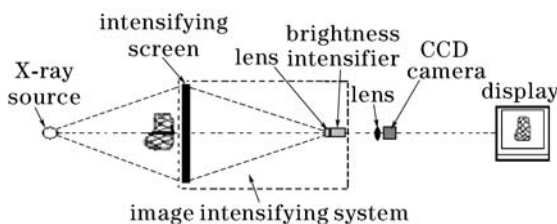


Fig. 1. Schematic diagram of the NXRIS.

where $P(\lambda)$ is the relative spectral distribution of the radiation, $R(\lambda)$ is the relative spectral distribution of the receiver.

The respective spectral response curves of the X-ray intensifying screens and the super S₂₅ photocathodes are shown in Fig. 2. We calculated the spectral matching factors of four different combinations between the X-ray intensifying screens and the photo cathodes and the values are given in Table 1. From the table, we can see that compared with the other three combinations, the group of the super S₂₅₂ photocathode and the Gd₂O₂S: Tb intensifying screen is obviously of the best spectral compatibility and can reduce the loss of radiation effectively, thus it is the best choice.

The NXRIS is a cascaded system^[4] and its spatial resolution depends on each component's spatial resolution. Supposing R_j is NXRIS resolution; R_a is filter's resolution; R_b is intensifying screen's resolution; R_c is the embedded lens resolution (its effective work area is

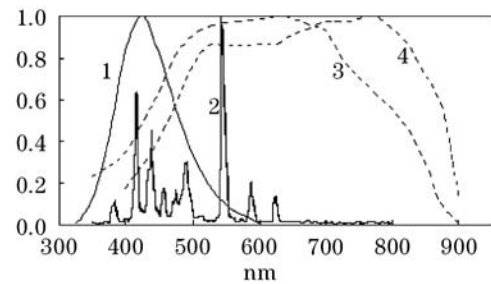


Fig. 2. Spectral response curves of photocathodes and intensifying screens. 1: CaWO₄ screen; 2: Gd₂O₂S:Tb screen; 3: super S₂₅₂; 4: super S₂₅₁.

Table 1. Spectral Matching Factors

Intensifying Screen	Peak Wavelength (nm)	Spectral Matching Factors for Different Combinations of Screen-Photocathode	
		Super S ₂₅₁	Super S ₂₅₂
Gd ₂ O ₂ S:Tb	545	0.644	0.761
CaWO ₄	425	0.369	0.571

$\phi 17.5$ mm) and R_{cb} is the embedded lens resolution diluted to the intensifying screen; R_d is the brightness intensifier resolution (its effective work area is $\phi 17.5$ mm) and R_{db} is the brightness intensifier resolution diluted to the intensifying screen. The resolution relation is given in

$$\frac{1}{R_j^2} = \frac{1}{R_a^2} + \frac{1}{R_b^2} + \frac{1}{R_{cb}^2} + \frac{1}{R_{db}^2}, \quad (2)$$

and the diluted coefficient

$$\alpha = \frac{17.5}{25.4 \times j} = \frac{0.69}{j}, \quad (3)$$

thus

$$R_{cb} = \alpha \cdot R_c, \quad \text{and} \quad R_{db} = \alpha \cdot R_d. \quad (4)$$

Equation (2) can also be written as

$$R_j = [Q + j^2 H]^{-\frac{1}{2}}, \quad (5)$$

where

$$Q = \frac{R_a^2 + R_b^2}{(R_a \cdot R_b)^2}, \quad \text{and} \quad H = \frac{R_c^2 + R_d^2}{(0.69 R_c \cdot R_d)^2}. \quad (6)$$

Equation (5) shows the system's spatial resolution R_j decreases with the system's increasing visual field.

Supposing the size of the X-ray intensifying screen is j inch in diameter, the screen projection on CCD is an inner tangent circle which is shown in Fig. 3, and the spatial resolution of NXRIS is N LP/cm, it can be calculated that the spatial resolution in the CCD diameter direction is $2.54jN$ LP. Under the ideal conditions, the numbers of the stripes projected in the vertical direction and the horizontal direction on the CCD are $2.54jN$ and $(4/3) \times 2.54jN$ respectively. Therefore, the total number of CCD pixels can be given in

$$g = \frac{4}{3} \times (2.54jN)^2. \quad (7)$$

To compensate the deviance from the theoretical value, a coefficient a is set, thus Eq. (7) can be revised as

$$G = \frac{4}{3} \times (2.54jNa)^2. \quad (8)$$

The X-ray imaging system of 9 inch Toshiba X-ray intensifier, whose lens is coupled to the 400 thousand pixels CCD, can attain the medical standard of 12 LP/cm. According to this, the coefficient $a = 2$ is calculated, Eq. (8) can be written as

$$G = 34.4 \times (jN)^2. \quad (9)$$

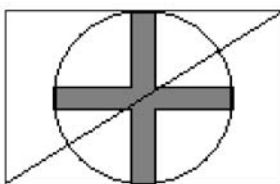


Fig. 3. X-ray intensifying screen projection on CCD.

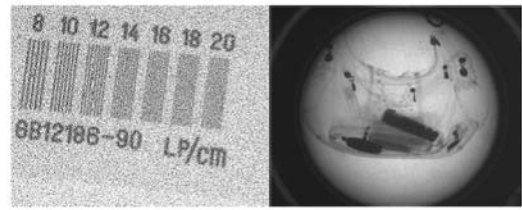


Fig. 4. Images produced by NXRIS.

Accordingly, the pixel amount G of the CCD can be calculated corresponding to different j and N . It can be calculated that when j is bigger than 17, the mega-pixel CCD must be used.

By the same method, the amount of scan lines of the display can be given^[5,6] in

$$S_{\parallel} = 5.1jN, \quad (10)$$

$$S_{\perp} = 6.8jN, \quad (11)$$

and it can be calculated that when j is bigger than 19, the horizontal scan lines must be over than 1000 lines.

Two images produced by NXRIS are given in Fig. 4. The left one is resolution stripe image and the right one is bag image. The images are clear enough to be widely used in security checking, non-destructive testing, industrial detection and other fields.

In conclusion, NXRIS is a combined optic-electronic system. Just for this reason, it can be taken apart and installed conveniently. The intensifying screen in this system matches well to the brightness intensifier, thus making sure that useful transmitted radiation is not lost. The technology of the digital image processing can not only bring us the image of high quality but also reduce the X-ray dose to the patient without the loss diagnostic information. It is possible that the image can be processed through the computer by choosing CCD. The X-ray imaging system has the advantages of low cost and big visual field, which is meaningful for the common users in the daily living.

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References

1. G. Shen, Chin. J. Medical Imaging Technol. (in Chinese) **16**, 607 (2000).
2. Б. К. Шмелев, *X-Ray Engine* (in Chinese) F. Ma and J. Yan (trans.) (Higher Education Press, Beijing, 1958).
3. E. H. Eberhardt, Appl. Opt. **7**, 2037 (1968).
4. S. Xiang and G. Ni, *The Principle of Photoelectronic Imaging Devices* (in Chinese) (National Defence Industry Press, Beijing, 1999).
5. S. Wu, *Neoteric Imaging Technology and Image Processing* (in Chinese) (National Defence Industry Press, Beijing, 1997).
6. W. Wang, (ed.) *TV Principle* (in Chinese) (Chongqing University Press, Chongqing, 2003).