Medical Imaging Detectors for Real-Time Micro-Radiography

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1. Introduction

Radiographic unsharpness results from geometric and detector unsharpness. Geometric unsharpness is affected by the size of the X-ray source in combination with source-to-object and object-to-detector distances. In conventional medical X-ray imaging using an X-ray tube, the highest spatial resolution is around 30 µm. However, this is attained by mammography that produces a single high-resolution radiograph using an intensifying screen and film combination.

On the contrary, micro-radiography with a resolution higher than 30 µm can be carried out using high-resolution detectors and a nearly parallel X-ray beam provided by a third generation synchrotron radiation source at SPring-8. In SR radiography, the long source-to-object distance and the small source size overcome geometric unsharpness.

A micro-radiography system has been investigated as a diagnostic tool for circulatory disorders and early stage malignant tumors. Digital micro-radiography with 10 µm resolution has been carried out at SPring-8 using two types of detectors designed for X-ray indirect and direct detection [1].

The indirect-sensing detector is a fluorescent-screen optical-lens coupling system using a high-sensitivity pickup-tube camera. A scintillator converts X-ray photons to visible light that is detected by the photoconductive layer of the pickup tube.

The direct-sensing detector consists of an X-ray direct-sensing pickup tube with a beryllium faceplate for X-ray incidence to the photoconductive layer. Absorbed X-rays in the photoconductive layer are directly converted to photoelectrons and signal charges are readout by electron beam scanning.

2. Indirect-sensing Detector

In Fig. 1, X-rays passing through an aluminum window are transformed into a visible image on a fluorescent screen. The screen is made from gadolinium oxysulfide (Gd_2O_2S:Tb) phosphor. The phosphor layer is about 20 µm in thickness. A mirror deflects the luminescent light 90˚ to a high numerical aperture lens system that focuses it on a video camera [2]. Light paths are folded with the mirror to protect the lenses and the camera from direct X-ray impact.

The image sensing device used is a high-sensitivity pickup-tube, HARPICON. The pickup tube consists of an amorphous selenium photoconductive target and is characterized by its internal amplification system which uses stable avalanche multiplication of photo-generated carriers under a strong electric field in the photoconductive layer [3]. The HARPICON tube is 64 times more sensitive than conventional tubes.

The input field of 20×20 mm on the screen is focused on a 10×10 mm photoconductive layer by the high numerical aperture lens system. The limiting resolution is 20 µm when the images are stored in 1024×1024 pixel digital format. The maximum speed of imaging is 30 images/sec in the 1050 scanning-line mode of the camera. The images are stored in a frame memory in 10-bit resolution.

The advantage of the indirect-sensing detector is that the fluorescent screen and lens can be changed quite easily. There are a few restrictions on the design of the input field size by adjusting the lens with an optimized demagnification factor under the condition of X-ray quantum-noise-limited imaging [4].

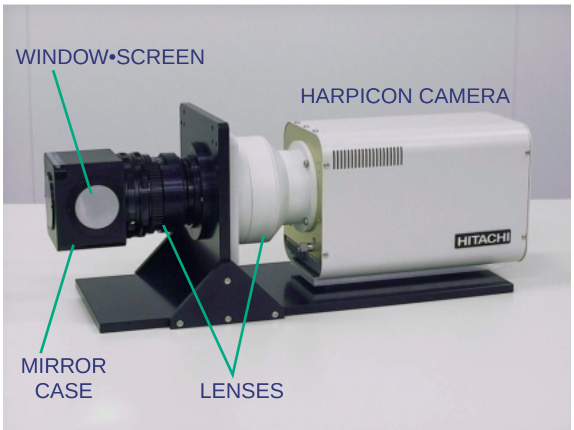

Fig. 1. View of X-ray indirect-sensing detector.

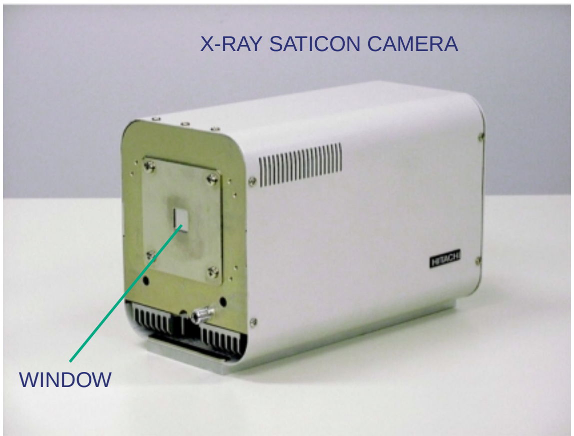

Fig. 2. View of X-ray direct-sensing detector.

3. Direct-sensing Detector

An X-ray direct-sensing vidicon-type pickup-tube camera was developed in the 1960's with a PbO photoconductive layer for the observation of real-time topography images combined with a high power X-ray generator. After that, the resolution of the direct-sensing pickup tube was improved. The X-ray SATICON tube with an amorphous photoconductive Se-As alloy target was developed for the use of synchrotron radiation experiments of live topography at the Photon Factory in Tsukuba [5].

The direct-sensing camera was further improved with the introduction of high-definition television (HDTV) which increases resolution to 1050 scanning lines. The new X-ray SATICON camera in Fig. 2 has the same resolution of 1050 scanning lines at present. However, the camera has been designed to improve its resolution to 2100 scanning lines.

The X-ray pickup tube was developed for higher resolution real-time imaging than the indirect-sensing detector using fluorescent-screen optical-lens coupling. The light scatter on the fluorescent screen is the dominant loss of resolution and this process is not present in the X-ray pickup tube. Charge carriers move in a path parallel to an electric field without deflection in the photoconductive layer. The spatial resolution of the direct-sensing tube depends only on the diameter of the scanning electron beam.

The new camera can take images at a speed of 30 images/sec. The digital images are acquired after analog-to-digital conversion synchronizing the timing with the electron beam scanning in the pickup tube. High-resolution images are stored in digital frame memory in 10-bit resolution at the maximum speed of imaging.

However, the disadvantage of the direct-sensing detector is that it does not have an iris. X-ray incident flux to the pickup tube should be adjusted to obtain an optimized output signal level from the camera.

4. Resolution of Detector

The performance of the direct-sensing pickup-tube camera was evaluated at the medium length bending-magnet beamline SPring-8 BL20B2 by taking an image of a spatial resolution chart. Images were obtained in the 1050 scanning-line mode of the camera at an input field size of 10×10 mm. Figure 3 displays a whole chart image in 1024×1024 pixel digital format. Figure 4 shows a digital zoomed image of the central portion in Fig. 3. The numerical values in Fig. 4 show the width of the stripes.

The limiting spatial resolution is about 10 μm equal to the pixel size on the photoconductive layer. By using this detector, small blood vessels with diameters of 20-30 μm can be visualized. The resolution will improve to 5 μm with a camera operated at a 2100 scanning-line mode. The image will be stored at a speed of 7.5 images/sec in 2048×2048 pixel digital format.

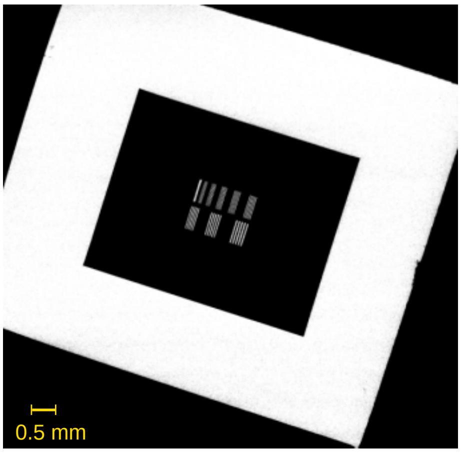

Fig. 3. Whole image of resolution chart.

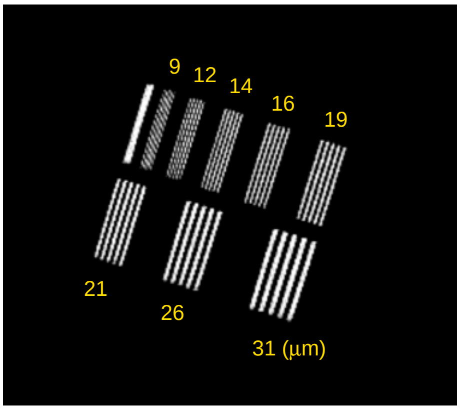

Fig. 4. Digital zoomed image of resolution chart.

References

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