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NUCLEAR SCIENCE AND TECHNIQUES

Nuclear Science and Techniques 19 (2008) 50–52

Two-dimensional X-ray imaging using plastic scintillating fiber array

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Abstract Due to its low cost, flexibility and convenience for long distance data transfer, plastic scintillation fiber (PSF) have been increasingly used in building detectors or sensors for detecting various radiations and imaging. In this work, the performance of using PSF coupled with charge-coupled devices (CCD) to build area detectors for 2D X-ray imaging is studied. We describe the experimental setup and show the obtained images from CCD. Modulation Transfer Function (MTF) of the PSF array is also presented and compared to earlier reports.

Key words Plastic scintillating fiber, X-ray imaging, MTF

CLC numbers TN25, O571.33

1 Introduction

As an important diagnostic and characterization tool, X-ray imaging has been increasingly adopted in medicine, biology, security and industrial applications[1]. Traditional technique based on X-ray film processing is replaced by digital imaging technique, which is advantageous in image quality, capability of imaging processing and analysis, and image transfer and management *via* internet. In a digital imaging system, X-ray transmission patterns are sampled in spatial and intensity dimensions by recording intensity of transmitted X-rays over a large array. However, most digital X-ray imaging detectors rely on scintillation technology that converts X-ray into visible lights, which are detected by CCD (Charge Coupled Device)[2].

Common scintillation materials are crystals, and the size is decided by the X-ray energy. Scintillation materials commercially available for constructing such an X-ray digital detector include cadmium tungstate ($CdWO_4$), cesium iodide (CsI) and bismuth germanate (BGO), etc[3-5]. A thicker detector is preferred for increasing detection efficiency or sensitivity, but a thick scintillator would result in larger isotropic spread of the lights generated in the detector, and this reduces spatial resolution of the imaging system, hence a compromise between the spatial resolution and X-ray absorption efficiency in designing the X-ray imaging system. Also, as far as the cost concerns, it is better to find a simple, inexpensive, and effective approach in constructing a digital X-ray imaging system.

An alternative approach is to use optical fibers to build an array plate coupled directly with a CCD[6]. In a scintillating fiber, a portion of light converted from X-rays is channeled along the fiber *via* total internal reflection, an extra mural absorber (EMA) would absorb the remainder[7]. The scattered radiation in a fiber causes a uniform background. Such a design, in principle, does not require any compromise of the fiber length and the spatial resolution. Plastic scintillation fiber (PSF), commercially available with various dimensions, is less expensive. More importantly, PSF is flexible and can be easily built into an array detector

Supported by National Natural Science Foundation of China (No.60602065)

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Received date: 2007-10-16

in geometry of the object to be imaged with optimized efficiency.

In this paper, performance of a PSF array coupled with a CCD is described.

2 Experimental

The experimental set-up consists of X-ray source, fiber array and CCD system (Fig. 1).

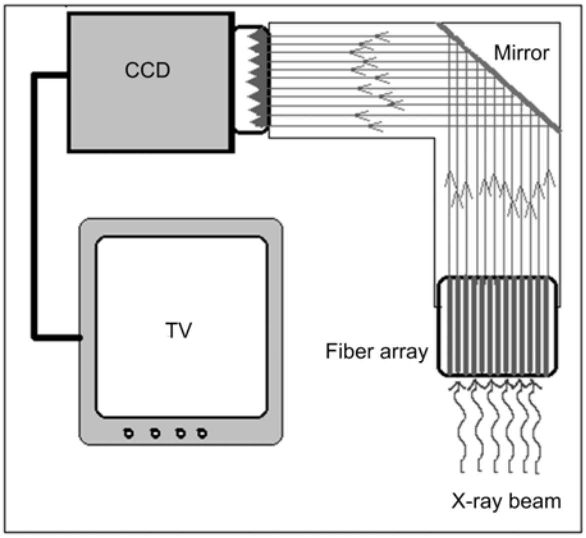

Fig. 1 Schematic of the experiment setup (coupling of the PSF array to CCD).

Peak voltage and current of the X-ray tube (tungsten anode) were respectively 65 kVp and 1.5 mA. The X-rays were collimated by a 1.5 mm aluminum collimator, which eliminates photons of less than 20 keV almost entirely. The filtering narrowed the spectrum (20-65 keV), and beam-hardening effect was negligible.

A two-dimensional PSF array (Fig.2a) is made with Φ1 mm BCF-10 fibers of 20 cm length, by Bicron Corp[7]. The fiber is polystyrene doped with 1% butyl–phenyl–byphenylyloxadiazole (PBD), with refractive index of 1.60 and density of 1.05 g·cm^{-3}. The cladding, about 3% of the fiber diameter, is polymethylmethacrylate (PMMA) with refractive index of 1.49. The numerical aperture of the fiber is 0.58, and the trapping efficiency is 3.44%. The fiber emits about 8000 photons per MeV. The light emission spectrum of the PSF is peaked at 432 nm. The decay time is 2.7 ns[7].

The CCD is Hamamatsu C5985[8], with a minimum sensitivity of 2.5×10^{-4} lx. It can be directly connected to TV set. The image processing could be done by computer software. An ADC (Analog to Digital Converter) card to convert the CCD signal and a frame grabber card was installed in a PC for data acquisition.

The CCD is sensitive to radiation, so the fiber bundle cannot be coupled directly to the CCD. To avoid damage to CCD by the incident X-rays, output lights of the fiber were reflected to the CCD window *via* a mirror, and the CCD camera and PSF array were assembled in L shape, as shown in Fig.2b. Such geometry protects the CCD, though the number of photons detected by the CCD is significantly reduced.

Different objects, including a radiator, marble, screw, and key, as shown in Fig.2b, too, were imaged by the experimental setup. The image contrast mainly depends on thickness of the object itself. Great care was taken to optimize the light-collection efficiency. The fiber array was covered by a black masking tape to avoid interference from background light. The fiber array, CCD and mirror were assembled as tightly as possible. And the fibers were strictly parallel to each other to limit crosstalk among neighboring fibers.

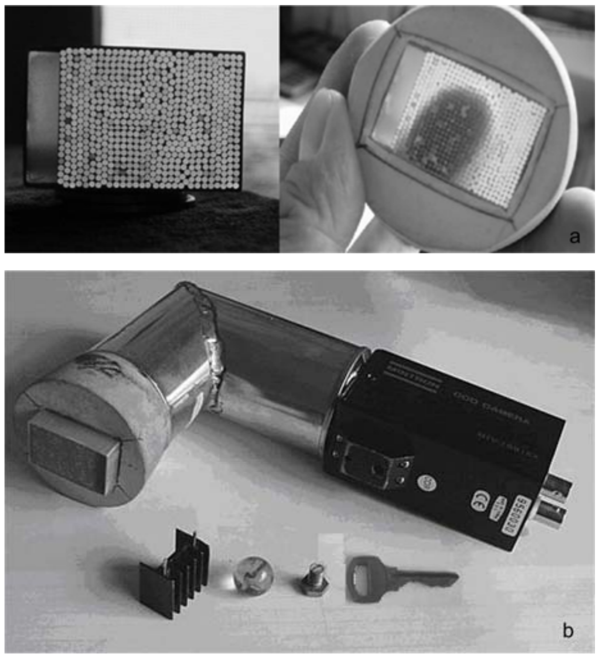

Fig.2 An array of the Φ1 mm plastic scintillation fiber (a) and L-shaped assembly of the CCD and PSF and imaging objects (a radiator, marble, screw and key). The L-shape was adopted to avoid damage to the CCD (b).

The object was placed between the X-ray source and the fiber array. The array axis was aligned to the

X-ray incidence. X-rays penetrating the object generate scintillation lights in the PSF. A portion of the lights propagated along the fiber and produced signals in the CCD. The number of photons depends on X-ray energy, intensity and optical properties of the PSF. The photon number detected by the CCD depends on the X-ray energy and intensity, trapping and transmitting efficiency of the fiber and efficiency of the CCD.

3 Results and discussion

Four simple objects, a radiator, marble, screw and key, were imaged to demonstrate effectiveness of the method. Post-processing of the image was used. The images processed by PhotoShop 7.0 are shown in Fig.3.

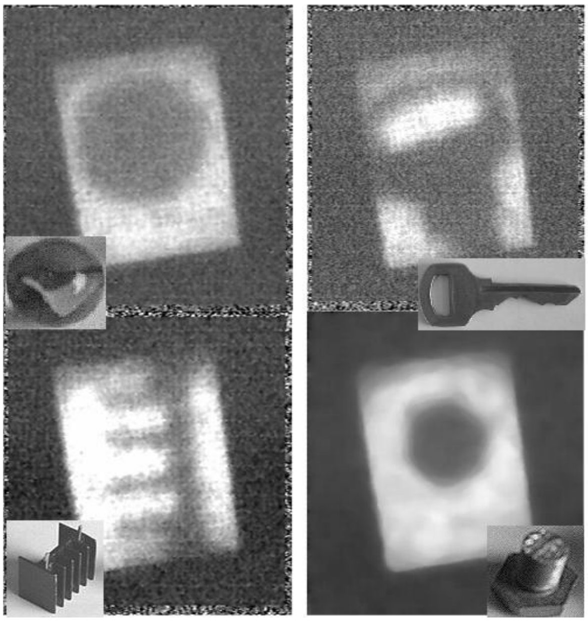

Fig.3 Four images taken by the PSF array.

Spatial resolution of an imaging device can be characterized by the point spread function and modulation transfer function (MTF)[9]. The MTF is a mathematical description of a system's capability to image the whole range of spatial frequencies in the object. In this paper, the quality of an imaging system is characterized by its MTF. MTF of this imaging system was calculated using an edge spread function (ESF) method, which is the result obtained by the imaging system in imaging an edge[9]. The MTF curve of the system is shown in Fig.4. According to the curve, the MTF of 20% is achievable for objects with spatial frequency of about 0.03 lp/mm. Resolution of the imaging system is a little worse than a previous work[10], where 20% MTF was achievable with frequency of 0.06 lp/mm using a single fiber for X-ray imaging. This degradation in resolution is probably due to the cross-talk effect in a fiber array. Using PSF of smaller diameter the resolution can be improved, as we will do in further experiments.

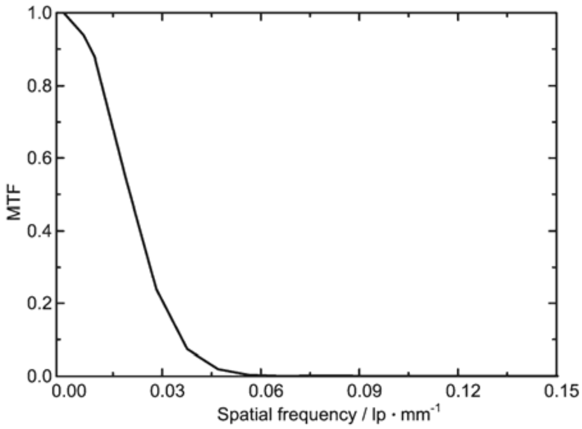

Fig. 4 MTF curve of the system.

In summary, comparing to available commercial computed tomography systems, the PSF array method is relative simple and low cost. If the PSF array can be better fabricated and there is no environmental drift (mainly by the mirror), the system should achieve more acceptable results and more application should be found in radiation imaging fields.

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