V. 1. Visualization of Radiation Distribution with High Sensitive CCD Camera

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Introduction

For tumor localization at early stage, we have developed an endoscopic probe using a small BGO scintillator coupled with an optical fiber which can detect gamma rays from tumor-seeking radiopharmaceuticals\(^1\)\(^2\). We are also proceeding to develop a beta-ray endoscopic probe using a plastic scintillator coupled with an optical image fiber. An invisibly small tumor can be localized by counting of gamma-ray and beta-ray pulses through a MCS (multi-channel scalar) during the subject's body scanning.

For routine use in clinical diagnostics, it is strongly needed to identify tumors instantly as visual images. The CCD (charge coupled device) camera is widely used to get a visual image for visible lights, but has too low sensitivity to get a visual image for scintillation lights from the radiation detector. We therefore introduced a high sensitive cooled CCD camera equipping two MCPs (multi-channel plates) and tested its performance.

Methods

The CCD camera is a cooled CCD camera with I. I. (Image Intensifier) implementing two MCPs (multi-channel plates), the HAMAMATSU C4880-92, fabricated by the Hamamatsu Photonix Co. Ltd. The MCP which is coated for UV fluorescence has 15% of quantum efficiency for light of the wave length between 200nm and 400nm. The CCD is a 12.2mm square size, full frame transfer type. In order to reduce the dark current, the CCD is cooled down -50°C lower than the room temperature by a peltier device. The resolution of the A/D converter is from 12bit to 14bit, and the minimum exposure time is 5ns. A C-mount lens for the TV camera, CANON VF12.5 1.4 (f=12.5mm, F=1:1.4) was attached to this camera and close rings were used if necessary. The digital output data from the A/D converter of CCD are transferred to a personal computer for constructing various two dimensional images.

In this study, we first investigated the performance of this CCD, such as linearity, stability, uniformity and sensitivity, then measured the direct visual images of scintillation
lights from NE102A plastic and liquid scintillation detectors irradiated by beta and gamma rays.

We also visualized the scintillation light images transported through an optical image fiber coupled with the NE102A scintillator.

Results and Discussions

Dark counts

First, we measured dark counts of the CCD covered with lens cap by varying the acquiring time, the CCD temperature and the MCP gain.

Dark counts come from the resetting noise and readout noise, and are approximately proportional to the acquiring time, and the square of the CCD absolute temperature and the MCP gain.

From this data, we determined the optimum values of these parameters.

Point source images with plastic scintillator

Point source images were observed with the CCD camera by measuring the scintillation lights from the 3mm thick NE102A plastic scintillator which was placed closely to point sources. Figure 1. shows the images of 9 gamma-ray point sources, $^{22}$Na, $^{57}$Co, $^{60}$Co, $^{152}$Eu, $^{88}$Y, $^{54}$Mn, $^{133}$Ba, $^{137}$Cs, $^{241}$Am from the top left to the bottom right. The left images are the visual images under the visible fluorescence light, the right images are the images of scintillation lights corresponding to the gamma-ray intensities under the dark root, and the middle images are the superposition of these two images.

The bright gamma-ray images from $^{152}$Eu and $^{137}$Cs sources and a faint gamma-ray image from $^{60}$Co source can only be seen in Fig.1, because these sources have about 5 times stronger intensities of 2.5$\mu$Ci than other sources of <0.5$\mu$Ci.

Collimated gamma-ray images with plastic scintillator

We measured scintillation images of the 3mm thick NE102A with the CCD camera by using collimated gamma rays of 100mCi $^{137}$Cs source. The collimator is made of 20cm long Pb blocks and have a slit of 0.5mm width, which makes a vertical fan gamma-ray beam. The scintillator was placed 3cm apart from the lens. A distance from the source to Pb blocks is 150mm, and from Pb blocks to NE102A is 100mm.(Fig.2-a).

The I. I. and MCP have some sensitivity for gamma rays. We got images by scintillation of NE102A(FWHM=1.22mm) and by direct irradiation to I. I. (FWHM = 1.62mm) as seen in Fig. 3. Because of the size of I. I. (12.2mm) which is smaller than that of NE102A (27.2mm, same size as CCD's view), the image of I. I. seems to be wider than scintillation image.
Imaging of V-shaped line gamma-ray source with liquid organic scintillator

We measured the scintillation images with a liquid organic scintillator by using a gamma ray line source. The line source was made of 11.1μCi ⁸⁵Sr in a capillary which has 0.5mm outer diameter. The line source has a shape of a letter "V". The liquid scintillator was sealed into a pair of 5mm thick glass plates with O-ring, which has 5mm thickness and 145mm diameter. The line source was set in contact with the glass.

The image shown in the lower photograph of Fig.4 represents a V-shaped line source, but spreads much wider than the original line source as seen in the upper photograph of Fig. 4. The FWHM of this image is 17.8mm as shown in the bottom graph of Fig. 4. This image spreading comes from a distance of source and detector, a reflection of scintillation on the surfaces of glass plates, and scattering of gamma rays and scintillation.

Scintillation image transported through optical image fiber

The scintillation light image was transported with an optical image fiber made by Olympus Optical Co. Ltd. The image fiber has 3.5mm effective diameter and 1m length, and is connected to 1mm thick NE102A scintillator with an optical silicon oil. The scintillator was irradiated with a collimated gamma-rays with 0.5mm width. As seen in Fig.2-b, a distance from a ¹³⁷Cs source to Pb blocks of 50mm length is 80mm, and that from Pb blocks to NE102A is 0mm. Another side of the image fiber was placed 3cm apart from the lens.

Figure 5 shows the collimated gamma-ray image due to the scintillation light transported through the image fiber. The 3.5mm diameter of image fiber is very small compared with the CCD's view of 27.2mm. The image transported with the image fiber has 1.33mm FWHM spatial resolution of the image which is only 10% wider than the 1.22mm FWHM of the image (Fig. 3) observed without the image fiber. This reveals that 1m long image fiber well transports the original image without spreading lights.

Conclusion

These observations clarified that the high sensitivity CCD camera can detect weak scintillation light of NE102A plastic scintillator as visual images and the image fiber can transport the scintillation light of NE102A as an image without spreading it.

We are now planning to apply this CCD camera system for a clinical radiation endoscope and a handy gamma-ray camera.

References

Fig. 1. An image with point sources. From top left they are $^{22}$Na, $^{57}$Co, $^{60}$Co, from middle left are $^{153}$Eu, $^{88}$Y, $^{54}$Mn from bottom left are $^{133}$Ba, $^{137}$Cs, $^{241}$Am. The left images are the visual images under the visible fluorescence light, the right images are the images of scintillation lights corresponding to the gamma-ray intensities under the dark room, and the middle images are the superposition of these two images. The another measuring condition were not recorded.

Fig. 2. Experimental geometry of a fan beam irradiation with Pb collimator. The upper graph is the experiment without the image fiber(Fig. 2-a) and the lower one is with the image fiber(Fig. 2-b).
Fig. 3. An image with a fan beam gamma ray. A MCP gain is 13. An irradiation time is the 10 min.

Fig. 4. An image with a liquid organic scintillator by using a V-shaped gamma-ray line source. The upper image is the visual image under the visible fluorescent light, the middle image is the image of scintillation lights under the dark room, the bottom graph is a profile of scintillation intensity between two horizontal lines of the middle image. A MCP gain is 13. This images of 100 sec irradiations are added 10 times.

Fig. 5. An image through a image fiber with a fan beam gamma ray. A MCP gain is 13. An irradiation time is 10 min.