J. Korea Asso. Radiat. Prot.
Vol. 29 No. 4 : 257~261 (2004)

◙ 論 文 ◙

Development of a Coded-aperture Gamma Camera for Monitoring of Radioactive Materials

Gyeseong Cho · Hyung Joo Shin · Yong Ki Chi and Jeong-Hyoun Yoon*
Korea Advanced Institute of Science and Technology
*Nuclear Environment Technology Institute

방사성 물질 감시를 위한 부호화 구경 감마카메라 개발

조규성 · 신형주 · 지용기 · 윤정현*
한국과학기술원
*원자력환경기술원

(2004년 9월 30일 접수, 2004년 11월 26일 채택)

Abstract - A coded-aperture gamma camera was developed to increase the sensitivity of a pin hole camera made with a pixellated CsI(Tl) scintillator and a position-sensitive photomultiplier tube. The modified round-hole uniformly redundant array of pixel size 13 x 11 was chosen as a coded mask considering the detector spatial resolution. The performance of the coded-aperture camera was compared with the pin hole camera using various forms of Tc-99m source to see the improvement of signal-to-noise ratio or the improvement of the sensitivity. The image quality is much improved despite of a slight degradation of the spatial resolution. Though the camera and the test were made for low energy case, but the concept of the coded-aperture gamma camera could be effectively used for the radioactive environmental monitoring and other applications.
Key words : gamma camera, pin hole, coded-aperture, sensitivity, Signal-to-noise ratio

요약 - 핀홀 감마카메라의 민감도를 향상시키기 위하여 픽셀화된 CsI(Tl) 섬광체와 위치민감형 광증배관을 이용하여 부호화 구경 감마카메라를 개발하였다. Rounded-hole로 이루어진 13 x 11 픽셀구조의 개조된 uniformly reductant array (URA) 가 계측기의 공간해상도를 고려하여 부호화된 마스크로 선택되었다. 부호화된 구경 카메라와 핀홀 카메라의 성능을 비교하기 위하여 Tc-99m 소스의 여러 가지 형태를 이용하여 테스트 하였으며, 신호 대 잡음비 또는 민감도의 향상에 대한 카메라의 성능을 분석하였다. 그 결과 공간해상도에 있어서 약간의 저하가 있었으나 영상의 질은 매우 향상되었다. 비록 카메라의 개발과 테스트가 저에너지 영역에서 이루어졌지만, 부호화 구경 카메라의 구상은 방사성 물질 감시 그리고 다른 응용들에 있어서도 효과적으로 사용되어질 수 있을 것이다.
중심어 : 감마카메라, 핀홀, 부호화 구경, 민감도, 신호대잡음비

Introduction

Gamma cameras have been used to monitor the nuclear material facility or to survey the contaminated area and to locate the high radioactivity source in the accident area. The conventional gamma camera uses a pin-hole collimator and a position-sensitive radiation detector such as the position-sensitive photo-multiplier tube (PSPMT). But because of the poor sensitivity of the pin-hole collimator, the longer measurement time is necessary to maintain the proper signal-to-noise ratio (SNR). If the size of pin hole gets larger, the sensitivity increases but the resultant spatial resolution becomes poorer. So rather than increasing the hole size, the collimator with many holes can be used in a certain way that the sensitivity can be increased without worsening the spatial resolution. The collimator with many holes or apertures in general have been used in the field of astrophysics imaging for a long time and is called as the coded-aperture mask. The figure 1 shows the conceptual process of imaging using the coded-aperture camera. The apertures should be arranged in a certain pattern so as to easily recover the original image from the overlapped image as accurately as possible. The objective of this study is to demonstrate that a typical gamma camera can be easily converted into the high efficient camera by using a coded-aperture collimator properly designed to fit the object energy range and the detector size and the required field of view (FOV).

Material and Methods

The detected discrete image can be expressed by using a mathematical convolution of 2-d array matrices as follows.

$$D = O * A + N \quad (1)$$

where D is the detected image array, O is the original object array, A is the coded aperture array, and N is the random noise. The * mark represents the convolution operation.

The ideal coded-aperture array consisted of pixels of 0 or 1, meaning the opaque and the transparent part respectively. The detected image D does never look like the original image O because as many images as holes on the aperture array are overlapped on the detector plane. So in general we need the inverse matrix of the array A. However, if the autocorrelation of the array A is a delta function, the only thing needed for decoding the detected image into the original one is to convolute the array D with the array A. Therefore,

$$D * A = O * A * A + N * A = O * \delta + N' \quad (2)$$

where δ means a delta function.

The arrays of which the autocorrelation is a delta function had been investigated by many researchers. According to literatures, random arrays, uniformly redundant arrays (URA) [1], hexagonal URA (HURA), modified URA (MURA) [2], pseudo-noise product (PNP) [3], M-P, M-M [4], No-Two-Hole-Touch (NTHT) [5] have been suggested. However, among them, URA is the most widely used one so far.

In this study, the 13 x 11 pixel URA array was chosen as a basic pattern by considering the intrinsic resolution of the PSPMT gamma camera in use, and the aperture mask of a mosaic pattern having 2 x 2 times of the basic pattern area, i.e. 26 x 22 pixels, was fabricated with a tungsten alloy plate (Korea Tungsten Inc. H40 model, 98W% tungsten, density

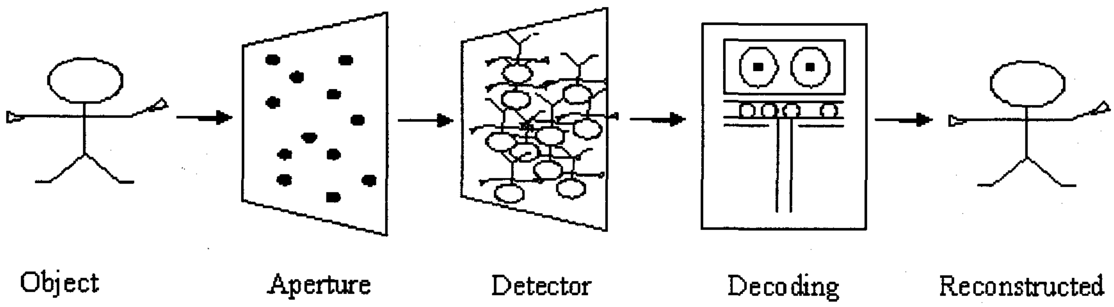

Fig. 1. The conceptual sketch of the coded aperture imaging process showing the coding and decoding processes.

18.5g/cm3). The reason to use the mosaic pattern is to maximize the field of view for a given size of the detector area.[1] The thickness of the aperture mask was determined to be 3mm for the low energy gamma-ray because the given gamma camera was originally designed for imaging the low energy gamma-ray sources. The pixel length of the square aperture is 2mm so that the mask size is 52mm x 44mm in total.

When an opaque part is surrounded by transparent parts, it will be off the mask. In order to avoid this practical problem occurred in the ideal square aperture mask, the corners of apertures were rounded as shown in the Fig. 2.

It was named as modified round-hole uniformly redundant array (MRURA). The performance of MRURA was simulated with MCNP and MATLAB prior to real fabrication.

The gamma camera consisted of a 5 inch diameter PSPMT, R3292 model, manufactured by Hamamatsu Photonics Inc, which had 28(X) + 28(Y) crossed-wire type anode and a CsI(Tl) scintillator pixellated as 2mm x 2mm x 3mm. Its basic functions were described in our previous publication.[6]

Finally in order to evaluate the performance of the developed coded-aperture gamma camera in the laboratory, Tc-99m, which is widely used in the nuclear medicine field, was used as the gamma source for various tests. At first in order to measure the signal to noise ratio, a point-like source was used for the same measurement time for both systems. then the peak signals to back ground noise ratio of the final images were compared. Then the resolution of the gamma cameras was measured by using a slit phantom. The resolution was defined as the full-width-at-half-maximum (FWHM) value of the line images. Finally as a demonstration of the qualitative evaluation of the image quality, a 'c' shaped phantom made of a thin glass tube was prepared.

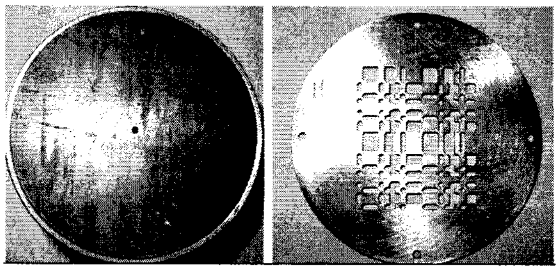

Fig. 2. Pin hole (left) and 13x11 MRURA collimator (right) made of 3mm thick tungsten plates.

Results and Discussion

First of all, we have simulated the MRURA and URA to check whether there is any significant degradation of the spatial resolution due to the rounded corner effect, but as shown in the table 1, there was no significant difference between two images obtained for MRURA and URA. This is likely due to the fact that the spatial resolution of the PSPMT coupled scintillator detector is so poor to show the small difference. The only difference between URA and MRURA was the number of photon counts. As expected, in the case of MRURA, about 15% of photon was lost compared to the URA case. However, its efficiency is still 6.5% higher than the case that every aperture is a circle.

Then the signal-to-noise ratio for both cameras was measured by using a point-like source located at 14 cm away from the aperture and the aperture to the detector was 7 cm. As seen in the Fig. 3. the ratio of the SNR of coded aperture camera to the SNR of the pin hole camera is 2188/sqrt(2188+6.73) / 50.5/sqrt(50.5+0.46) = 46.7/7.07 = 6.6.

Table 1. Comparison of the number of photons passing though different type of apertures.

	Ideal URA	Modified round-hole URA	1.84mm square hole with 0.08mm grid	Round-hole URA
Signal/ratio (%) (Arbitrary unit)	1136/(100%)	964.5/(85%)	961.5/(85%)	892.2/(78.5%)

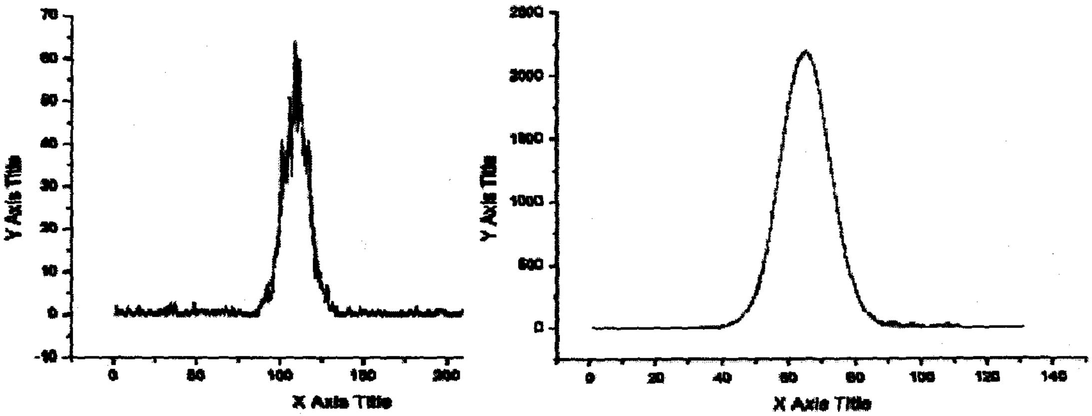

Fig. 3. The cross-sectional data of a point-like source image measured by the pin hole camera (left) and the coded-aperture camera (right). Red lines are fitting curves with a Gaussian form.

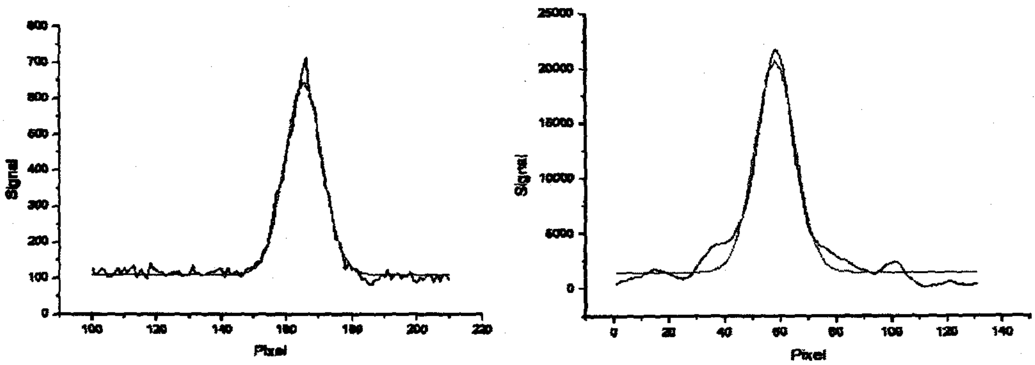

Fig. 4. The cross-sectional data of slit phatom images measured by the pin hole camera (left) and the coded-aperture camera (right). Red lines are fitting curves with a Gaussian form.

The theoretical expression of the SNR for the pin hole camera can be given as follows:

$$SNR_p(i,j) = \frac{S_{ij}}{\sqrt{S_{ij} + B}} \tag{3}$$

where the S_{ij} is the ij-th point data in the object and B is the background data. The theoretical expression of the SNR for the coded-aperture image is given[7] as follows:

$$SNR_u(i,j) = \frac{\sqrt{N} S_{ij}}{\sqrt{S_{ij} + I_T + 2B}} \tag{4}$$

where the noise expressed as three terms, which are the source contribution, the overlapping effect and the background effect. I_T is the sum of all S_{kl} except S_{ij}, which propagates through the reconstruction process because the images are overlapped to each other, and the N is the number of apertures in the collimator, which sets the number of the maximum overlaps. So the SNR of the multi-hole camera increases as the number of holes increases under the assumption that the background is constant over time and the measurement time is fixed.

The resolution measured by the spread of the slit phantom image are given in the Fig. 4 and the FWHM of the pin hole camera is 12.3 pixels but that of the coded-aperture camera was 14.3. So there is observed a slight degradation of the

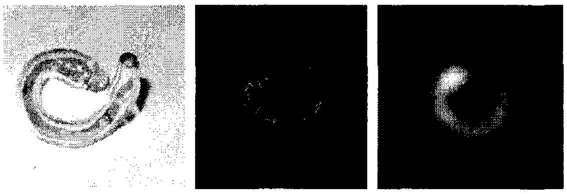

Fig. 5. The pin hole camera image (center) and the coded-aperture image (right) of a Tc-99m source filled in a 'c' shaped tube (left) for 10 minutes. The properties of the CsI(Tl), CWO,

spatial resolution for the case of the coded-aperture camera. Finally for the qualitative comparison, the images obtained by both camera are shown in the Fig. 5, where the significant improvement of the image quality is easily found.

Conclusion

Based on the PSPMT and a 13 x 11 MRURA pattern, a compact coded-aperture gamma camera was developed and its tests using Tc-99m source demonstrated the superior SNR. Though the camera and the test were optimized for the low energy gamma-ray, the similar gamma camera using a larger FOV and thicker aperture can be adequately used for the environmental monitoring of radioactive materials which has the energy range up to a few MeV.

Acknowledgements

This work has been carried out by the support from the KOSEF ERC program of the innovative technology center for radiation safety (iTRS).

Reference

1. E.E. Fenimore and T.M. Cannon, "Coded aperture imaging with uniformly redundant arrays", Appl. Opt., 17, 337(1978)
2. S.R. Gottesman and E.E. Fenimore, "New family of binary arrays for coded aperture imaging", Appl. Opt., 29, 4344(1989)
3. S.R. Gottesman and E.J. Schneid, "PNP-A New Class of Coded Aperture Arrays", IEEE Trans. Nucl. Sci. NS-33, 745-749(1986)
4. K. Byard, "On self-supporting coded aperture arrays," Nucl. Instr. and Meth. A 322, 97-100 (1992)
5. R. Accorsi, F. Gasparini and R.C. Lanza, "Optimal coded aperture patterns for improved SNR in nuclear medicine imaging", Nucl. Instr. and Meth. A 474, 273-284(2001)
6. W. Lee, G. Cho, and H. Kim, "A radiation monitoring system with capability of the gamma camera imaging and the estimation of exposure dose rate," IEEE Trans. Nuc. V.49(3), 1547-1551(2002)
7. E.E. Fenimore, "Coded aperture imaging: predicted performance of uniformly redundant arrays", Appl. Opt., 17, 2562(1978)