Annual Report of Iwate Medical University
Center for Liberal Arts and Sciences
No. 42(2007), 1 - 5.

Photon-counting x-ray computed radiography system utilizing a cadmium telluride detector

Eiichi Sato[a], Seiichiro Nomiya[b], Keitaro Hitomi[c], Hideaki Onabe[b],
Toshiaki Kawai[d], Akira Ogawa[e], Shigehiro Sato[f] and Toshio Ichimaru[g]

(Received October 26, 2007)

Abstract

The construction of a photon-counting x-ray computed tomography (CT) system utilizing a cadmium telluride (CdTe) detector is described. The CT system is of the first generation type and consists of an x-ray generator, a turn table, a translation table, a motor drive unit, a CdTe detector, two amplifiers, multi-channel analyzer (MCA), and a personal computer (PC). Tomography was performed by the repetition of the translation and rotation of an object. Penetrating x-ray spectra from an object are measured by a spectrometer utilizing a CdTe detector and a MCA, and both the photon energy and the energy width are determined by the MCA.

Keywords: x-ray CT, CdTe detector, single detector, first generation CT, photon-counting CT, biomedical tomograms

1. Introduction

Monochromatic x-ray generators have been developed corresponding to specific radiographic objectives. To perform high-speed radiography, we have developed monochromatic flash x-ray generators[1-7] with x-ray durations less than 1 μs. In particular, we have confirmed the irradiation of clean K-series characteristic x-rays and their harmonics from weakly ionized linear plasmas. Next, steady-state monochromatic x-rays[8,9] are also useful for performing mammography, iodine K-edge angiography,[10-12] gadolinium K-edge angiography, and x-ray fluorescence analysis of low-density atoms in biomedical objects.

Monochromatic radiography can be performed utilizing photon-counting imaging by selecting the

a Department of Physics, Iwate Medical University, 2-1-1 Nishitokuta, Yahaba 028-3694, Japan
b Raytech Inc., 5-6-27 Youtou, Utsunomiya 321-0904, Japan
c Department of Electronics and Intelligent systems, Tohoku Institute of Technology, 35-1 Yagiyama Kasumi-cho, Taihaku-ku, Sendai 982-8577, Japan
d Electron Tube Division #2, Hamamatsu Photonics K. K.., 314-5 Shimokanzo, Iwata 438-0193, Japan
e Department of Neurosurgery, School of Medicine, Iwate Medical University, 19-1 Uchimaru, Morioka 020-8505, Japan
f Department of Microbiology, School of Medicine, Iwate Medical University, 19-1 Uchimaru, Morioka 020-8505, Japan
g Department of Radiological Technology, School of Health Sciences, Hirosaki University, 66-1 Honcho, Hirosaki 036-8564, Japan

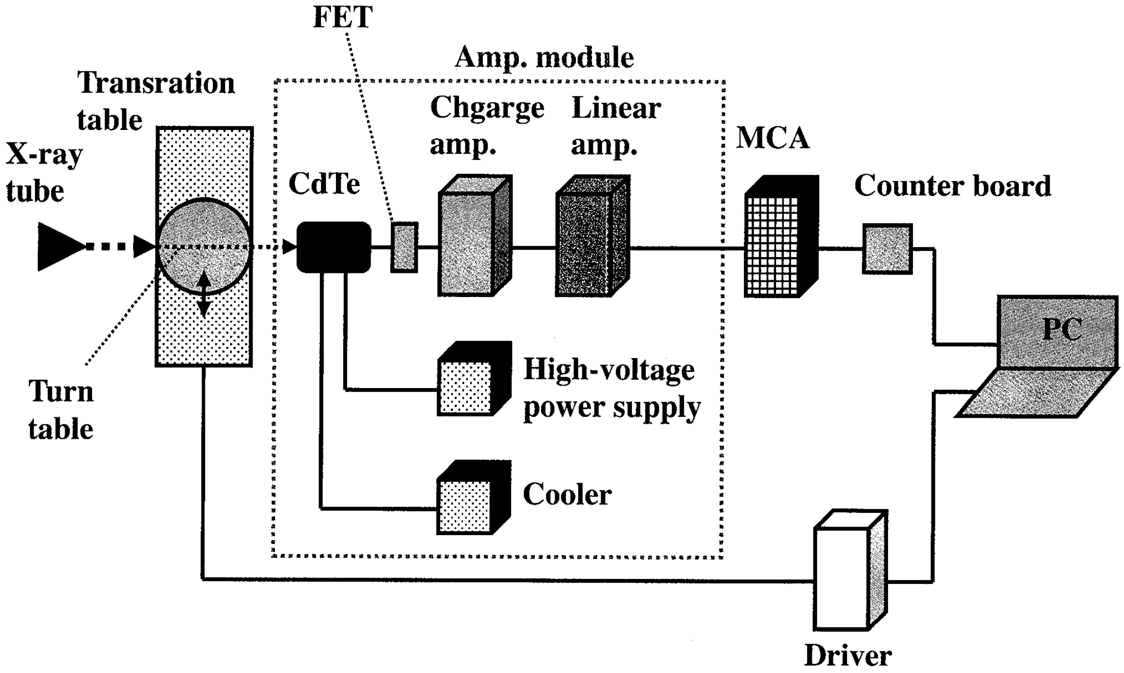

Fig. 1. Block diagram of a photon-counting x-ray CT system utilizing a CdTe detector.

photon energy and by controlling the energy width. Using a CdTe detector in conjunction with a MCA, monochromatic photon-counting radiography can be performed using polychromatic x-rays.

In this paper, we report a photon-counting x-ray CT system utilizing a CdTe detector, used to perform preliminary energy-selective biomedical tomography.

2. Photon-counting x-ray CT system

Figure 1 shows the block diagram of a photon-counting x-ray CT system utilizing a CdTe detector (Fig. 2). The CT system is of the first generation type and consists of an x-ray generator, a turn table, a translation table, a motor drive unit, the CdTe detector, two amplifiers, a MCA, and a PC. Tomography was performed by the repetition of the translation and rotation of an object. The turn and the translation tables are driven by two motors, respectively. Penetrating x-ray spectra from an object are measured by a spectrometer utilizing a CdTe detector and a MCA, and both the photon energy and the energy width are determined by the MCA for counting photons. The pitches of translation and rotation are selected corresponding to the objectives, and the spatial resolution improves with decreasing the two pitches.

3. Γ-ray spectra from an Am241

In order to measure γ-ray spectra for determining the photon energy, we employed a CdTe detector in the CT system. The count and the channel number are proportional to the relative photon number and the photon energy, respectively. We observed typical γ-ray spectra of 26.3 and 59.5 keV from an americium radioisotope (Am241) (Fig. 3). Therefore, penetrating x-ray spectra from the object are measured, and photon counting CT can be performed.

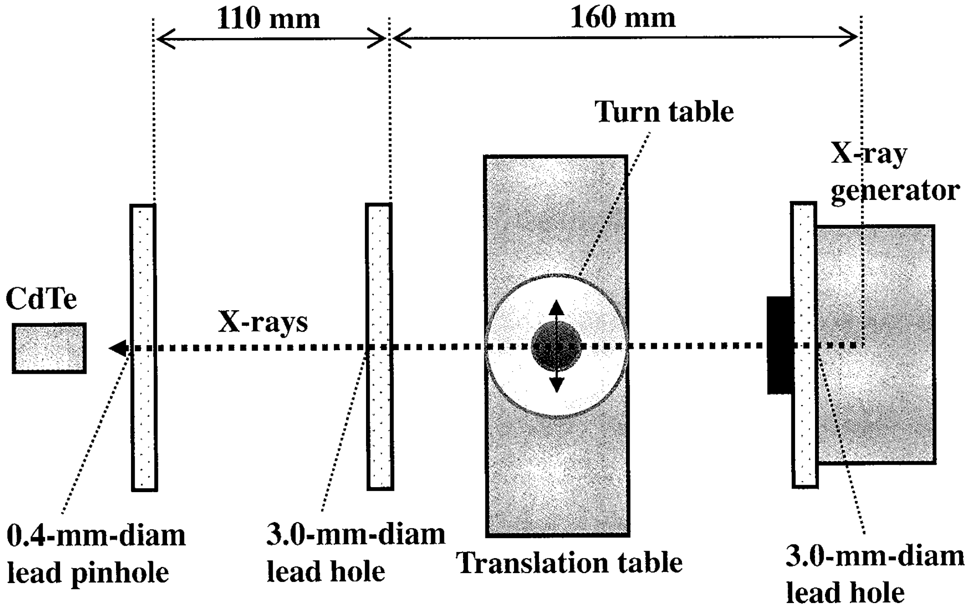

Fig. 2. Experimental setup for photon counting.

4. Tomography

Photon-counting CT was performed with a tube voltage of 60 kV using a 3.0-mm-thick aluminum filter. Figure 4 shows x-ray spectra and tomograms of a PMMA phantom filled with iodine medium (water) with an iodine density of 35 mg/mL. These x-ray spectra were measured after penetrating an iodine-based contrast medium, and the iodine K-edge and photon pileups were observed. Using all photons with energies from 20 to 60 keV, a PMMA phantom is seen, and the iodine medium is observed with high contrasts. Next, the image contrast of the PMMA phantom falls using photons with energies from 37 to 60 kV.

5. Conclusions and outlook

We developed the photon-counting x-ray CT system with the CdTe detector and performed CT with energies from 20 to 60 keV. In this CT system at a constant tube voltage and a tube current, the x-ray exposure time for obtaining one tomogram increases with decreases in the pitches of the translation and rotation and with increases in the counting time. However, the time can be decreased using the interpolation between the data points.

This CdTe detector used in this

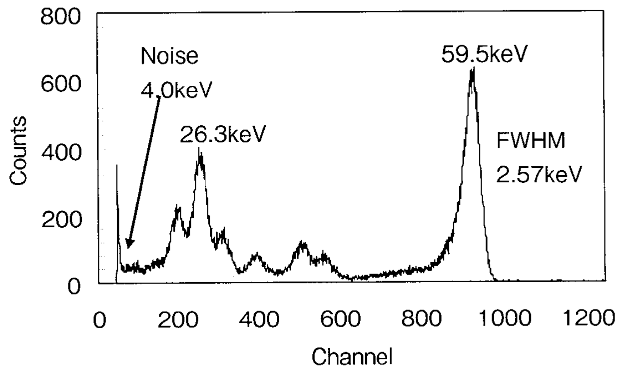

Fig. 3. Γ-ray spectra from an Am241. The channel number is proportional to the photon energy mostly.

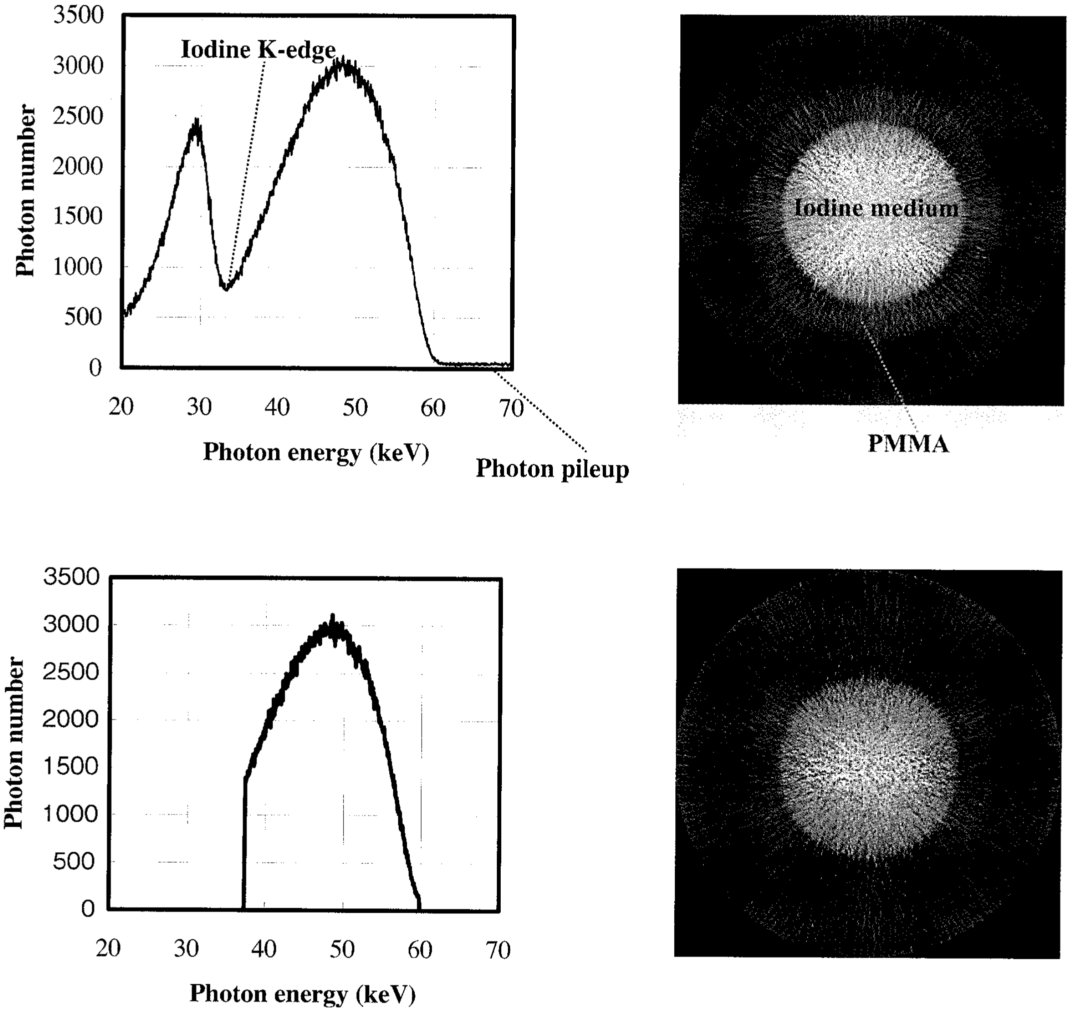

Fig. 4. X-ray spectra and tomograms of a PMMA phantom filled with iodine contrast medium with an iodine density of 35 mg/mL (a) using a photon energy range from 20 to 60 keV and (b) a range from 37 to 60 keV.

experiment detects x-ray photons with energies from 5 to 150 keV, and various biomedical objects can be imaged using optimum x-ray spectra discriminated by the MCA. Subsequently, the third generation type photon-counting CT utilizing a CdTe line detector is useful for decreasing the exposure time. Lately, several different drug delivery systems (DDS) have been developed and can be applied to diagnose cancers in molecular imaging. In view of this situation, an x-ray fluorescence CT utilizing photon counting is useful for cancer diagnosis because several drugs accumulate in cancers with low densities.

Acknowledgments

This work was supported by Grants-in-Aid for Scientific Research and Advanced Medical Scientific Research from MECSST, Health and Labor Sciences Research Grants, Grants from the Keiryo Research Foundation, The Promotion and Mutual Aid Corporation for Private Schools of Japan, the Japan Science and Technology Agency (JST), and the New Energy and Industrial Technology Development

Organization (NEDO).

References

1. E. Sato, M. Sagae, E. Tanaka, Y. Hayasi, R. Germer, H. Mori, T. Kawai, T. Ichimaru, S. Sato, K. Takayama and H. Ido, "Quasi-monochromatic flash x-ray generator utilizing a disk-cathode molybdenum tube," *Jpn. J. Appl. Phys.*, **43**, 7324-7328 (2004).
2. E. Sato, E. Tanaka, H. Mori, T. Kawai, T. Ichimaru, S. Sato, K. Takayama and H. Ido, "Compact monochromatic flash x-ray generator utilizing a disk-cathode molybdenum tube," *Med. Phys.*, **32**, 49-54 (2005).
3. E. Sato, Y. Hayasi, R. Germer, E. Tanaka, H. Mori, T. Kawai, T. Ichimaru, S. Sato, K. Takayama and H. Ido, "Sharp characteristic x-ray irradiation from weakly ionized linear plasma," *J. Electron Spectrosc. Relat. Phenom.*, **137-140**, 713-720 (2004).
4. E. Sato, Y. Hayasi, K. Kimura, E. Tanaka, H. Mori, T. Kawai, T. Inoue, A. Ogawa, S. Sato, K. Takayama, J. Onagawa and H. Ido: Enhanced K-edge angiography utilizing tantalum plasma x-ray generator in conjunction with gadolium-based contrast media, *Jpn. J. Appl. Phys.*, **44**, 8716-8721 (2005).
5. E. Sato, Y. Hayasi, R. Germer, E. Tanaka, H. Mori, T. Kawai, T. Inoue, A. Ogawa, S. Sato, K. Takayama and J. Onagawa, "X-ray spectra from weakly ionized linear copper plasma," *Jpn. J. Appl. Phys.*, **45**, 5301-5306 (2006).
6. E. Sato, Y. Hayasi, E. Tanaka, H. Mori, T. Kawai, T. Inoue, A. Ogawa, S. Sato, K. Takayama, J. Onagawa and H. Ido, "K-edge angiography utilizing a tungsten plasma x-ray generator in conjunction with gadolinium-based contrast media," *Rad. Phys. Chem.*, **75**, 1841-1849 (2006).
7. M. Sagae, E. Sato, E. Tanaka, H. Mori, T. Kawai, T. Inoue, A. Ogawa, S. Sato, K. Takayama, J. Onagawa and H. Ido, "Intense clean characteristic flash x-ray irradiation from an evaporating molybdenum diode," *Opt. Eng.*, **46**, 026502-1-7 (2007).
8. E. Sato, E. Tanaka, H. Mori, T. Kawai, T. Inoue, A. Ogawa, S. Sato, K. Takayama and J. Onagawa, "Characteristic x-ray generator utilizing angle dependence of bremsstrahlung x-ray distribution," *Jpn. J. Appl. Phys.*, **45**, 2845-2849 (2006).
9. E. Sato, E. Tanaka, H. Mori, T. Kawai, T. Inoue, A. Ogawa, M. Izumisawa, K. Takahashi, S. Sato, T. Ichimaru and K. Takayama, "Super-charcteristic x-ray generator utilizing a pipe and rod target," *SPIE*, **6319**, 63190Q-1-6 (2006).
10. E. Sato, E. Tanaka, H. Mori, T. Kawai, T. Ichimaru, S. Sato, K. Takayama and H. Ido, "Demonstration of enhanced K-edge angiography using a cerium target x-ray generator," *Med. Phys*, **31**, 3017-3021 (2004).
11. E. Sato, A. Yamadera, E. Tanaka, H. Mori, T. Kawai, F. Ito, T. Inoue, A. Ogawa, S. Sato, K. Takayama, J. Onagawa and H. Ido, "X-ray spectra from a cerium target and their application to cone beam K-edge angiography," *Opt. Eng.*, **44**, 096502-1-6 (2005).
12. E. Sato, E. Tanaka, H. Mori, T. Kawai, T. Inoue, A. Ogawa, A. Yamadera, S. Sato, F. Ito, K. Takayama, J. Onagawa and H. Ido, "Variations in cerium x-ray spectra and enhanced K-edge angiography," *Jpn.* J. *Appl. Phys.*, **44**, 8204-8209 (2005).