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Feasibility study on dual-energy X-ray computed tomography

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Introduction

Dual energy X-ray computed tomography (CT) gives quantitative information on electron density [1], which plays an important role in treatment planning for heavy ion radiotherapy. The goal of this study is development of technique for the dual energy X-ray CT that is applicable to an examinee.

Dual-energy X-ray CT using image-intensifier

Experimental Setup

The setup was installed at the beamline of NE5A of PF-AR. A Si(220) dual crystal monochromator was used. The second crystal had an asymmetry reflection plane with an angle of 4° with respect to the (220) plane. A sample was mounted on a rotation table. The 4-inch image-intensifier was located after the sample. It was mounted on a sliding table that shifted about 30 cm perpendicularly with respect to the beamline. Polyethylene blocks were put at front of the sample to decrease the beam intensity according to sensitivity of the image-intensifier. The incident X-ray energy spectrum was continuously measured using an NaI(Tl) crystal by detecting photon scattered from a thin aluminum foil.

Experiments

The monochromatic X-ray field of 40 mm by 70 mm was obtained by the double crystal monochromator, which has the asymmetrically cut second crystal. The magnification ratio of the vertical field size was 13.6 at 40 keV. Both the crystal surfaces were polished in order to increase the reflected intensity from the crystal at the sacrifice of energy resolution. In the case of fully tuning the monochromator for 40 keV, the ratio of 80 keV photons 40 keV photons was about 8 %. Detuning the monochromator or inserting a copper filter into the beamline can change the ratio arbitrarily. Two kinds of X-ray beams with the different ratio are equivalent to two monochromatic X-rays of 40 keV and 80 keV.

Samples for the dual-energy X-ray CT were phantoms which simulate electron densities of human tissues and solutions of dipotassium hydrophosphate (K_2HPO_4). Two kinds of X-ray beams were used. One was produced detuning the second crystal to decrease 80 keV photons. Another was produced by inserting 2 mm thick copper plate upstream of the monochromator to decrease 40 keV photons. In the former case, the ratio of 40 keV photons to 80 keV photons was 2.2. Originally, the flux of 40 keV was much more than that of 80keV, but the 40 keV flux was strongly decreased by polyethylene blocks put in front of the sample. The photon flux density was about 5×10^5 ph/s/mm^2 at the samples. The latter contained only 80 keV photons and the 40 keV photons were negligible.

When X-rays are parallel, a rotation of from 0° to 180° is sufficient for a CT scan. 360 views were taken for 180° in 0.5° interval in one scan. Two scans were done at each X-ray beam without change in the geometry. Since the image-intensifier has the ambiguity of 5 ms in the shutter speed in an external-trigger mode, we set exposure time more than 500 ms for each view.

Sensitivity of image-intensifier for a monochromatic X-ray

The sensitivity should depend on the energy of X-ray. Since the scintillator of the image-intensifier is mainly composed of CsI, the sensitivity for 40 keV X-ray is supposed to be higher than that for 80 keV X-ray. The ratio of sensitivity for 40 keV to that for 80 keV is experimentally determined by measuring well known linear attenuation coefficients of a material such as water using X-ray beam in which the X-ray flux of 40 keV and 80 keV are mixed by a known ratio. We found out the sensitivity ratio was 2.52 by measuring the linear attenuation coefficients of water. This value agrees with the values measured at BL14C1.

Results

We derived the linear attenuation coefficients of the samples for X-ray of 40 keV and 80 keV from CT images. The average ratios of the measured value to the theoretical ones are as follows; for Phantom –0.13±3.20% at 40keV, –1.17±2.23% at 80 keV, for K_2HPO_4 –1.83±2.32% at 40 keV, and –4.75±3.19% at 80 keV.

Summary

We measured the linear attenuation coefficients with X-ray beams in which 40 keV X-ray photons and 80 keV X-ray photons were mixing. The values are well in agreement with the theoretical values. In the experiments the dual-energy X-ray was obtained by using the second order harmonic photons from Si(220) planes as well as the first order harmonic photons simultaneously. This method shall be useful for a clinical diagnosis.

References

[1] M. Torikoshi et al., J. Bio. Opt. 6, (2001) in print.

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