Material discriminated X-ray CT system by using new X-ray imager with energy discriminate function

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ABSTRACT

Material discriminated X-ray CT system has been constructed by using conventional X-ray tube (white X-ray source) and photon-counting X-ray imager as an application with energy band detection. We have already reported material identify X-ray CT using K-shell edge method elsewhere. In this report the principle of material discrimination was adapted the separation of electron-density and atomic number from attenuation coefficient mapping in X-ray CT reconstructed image in two wavelength X-ray CT method using white X-ray source and energy discriminated X-ray imager by using two monochrome X-ray source method.

The measurement phantom was prepared as four kinds material rods (Carbon(C), Iron(Fe), Copper(Cu), Titanium(Ti) rods of 3mm-diameter) inside an aluminum(Al) rod of 20mm-diameter. We could observed material discriminated X-ray CT reconstructed image, however, the discrimination properties were not good than two monochrome X-ray CT method. This results was could be explained because X-ray scattering, beam-hardening and so on based on white X-ray source, which could not observe in two monochrome X-ray CT method. However, since our developed CdTe imager can be detect five energy-bands at the same time, we can use multi-band analysis to decrease the least square error margin. We will be able to obtain more high separation in atomic number mapping in X-ray CT reconstructed image by using this system.

Keywords: X-ray, CT, Material discrimination, energy discrimination, photon counting

1. INTRODUCTION

X-ray computer tomography (CT) is widely used on the site of an up-to-date medical treatment be-cause the cross section photograph is very useful for the diagnosis in the medical. However, the detector arrays of the charge accumulation type with no energy distinction function have been widely used for CT, because it corresponds to a high X-ray incidence rate and cost problem. Therefore, we proposed photon-counting type CT system by using new high-speed photon-counting CdTe im-aging device, which developed in our laboratory, corresponded to a high-speed operation. Then, we can find a lot of domination points in this system. The most advantage point in this photon-counting CT is very good pictures were reconstructed only by a simple calculation faithful to the principle, filtered-back projection method.

Individual light such as X-ray, infrared, and ultraviolet is useful by various scenes like the medical treatment, the material processing, and the measurement, etc. including imaging. Especially, X-ray imaging has been widely used for physical measurement, medical imaging, security services, nuclear monitor, and so on using its penetration properties of X-ray [1].

X-rays imaging are usually detected with the semiconductor detector in the “charge accumulation mode” as well as imaging of visible light. However, X-ray photon has very high energy compare with photon of visible light. In the case of visible light, one photon makes one hole-electron pair because the energy of the photon is the same level as the band gap. Therefore, the output current by number of carriers is proportional to the number of photons. X-ray photon, which has very high energy, makes many hole-electron pairs in semiconductor detector, for example about 30,000 pairs are generated by 120keV X-ray photon in CdTe detectors [2]. The penetrating X-ray photons have energy different in each photon so that a usual X-ray source may have a spectrum near white. Even if energy is different it, one photon becomes one hole-electron pair if it is visible light, it is unquestionable in usual case. However, the output current (number of charges) does not become constant even if the number of input photons is constant, because different energy X-ray photons generate the charges of a different number. Therefore, photon-counting method is very significance for an X-ray imaging, because this phenomenon is a big problem since it becomes a noise element on the image [3].

Moreover, if we can measure the number of charges of generation for one photon, we can understand the energy of the photon. We can obtain the radiation energy spectrum of incidence X-rays, when the histogram is made by using this principle [4-6]. In this paper, we introduce these pho-ton-counting X-ray imaging and photon-counting X-ray computer tomography (CT) as an application of X-ray imaging.

2. PHOTON COUNTING X-RAY IMAGING

In the photon-counting imaging, the maximum count rate limits the dynamic range since its mini-mum is zero. Fig. 1 shows the measurement count rate for current of X-ray source tube in our developed device [7]. The estimated minimum count rate to secure enough signal-noise ratios (SNR) in penetration images are about 1Mcps because the current means the number of X-ray photons. The imager has the performance that exceeds this rate as shown in

Fig. 1.

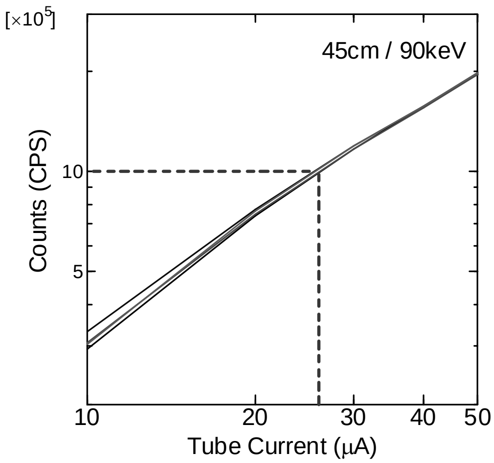

Fig. 1 Response property of imager for X-ray counts controlled by X-ray source tube current.

It is unexpectedly difficult to obtain “low-noise” and “high-contrast” image in X-ray penetration im-aging because an X-ray photons with various energy are incidence in the imager in general case as shown in the introduction. The clear image was obtained as shown in Fig. 2.

Fig. 2 X-ray penetration image of 500-yen coin.

The object of this penetration image was Japanese 500-yen coin made from copper, zinc and nickel. The image emphasis processing is given to these images because the average thickness of the coin is about 1.8 mm and the minimum difference of point of leaf is only 50 mm. The image emphasis processing was often treatable without trouble. It has proven the linearity and SNR of this device to be high. The result of material emphasis imaging by using energy discriminated photon-counting imaging is shown Fig. 3. Copper, molybdenum and gold were able to be distinguished. The main specification and block diagram are shown in Table 1 and Fig. 4 respectively.

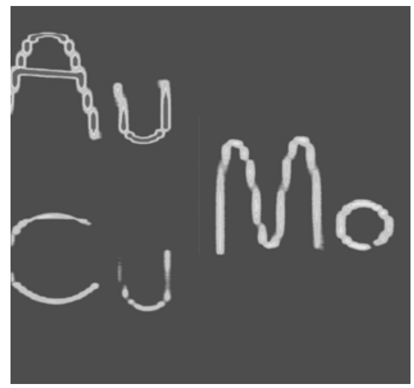

Fig. 3 Material discriminated X-ray penetration image of coupper (Cu), Molybdenum (Mo), and Gold (Au).

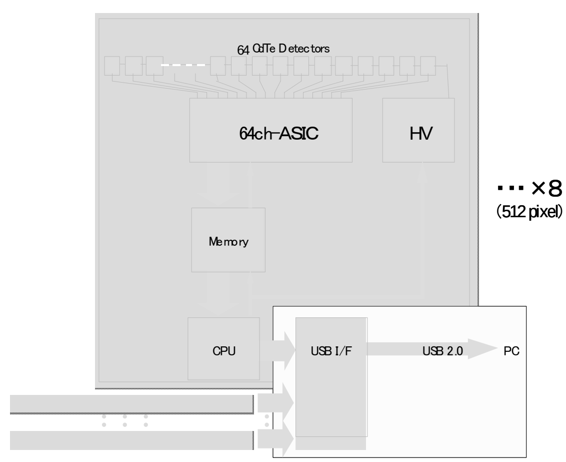

Fig. 4 Block diagram of 512 pixels X-ray imag-ing device.

3. MATERIAL DISCRIMINATED X-RAY CT

In X-ray penetration imaging, we can measure only total amount of adsorption in selected energy range even if using energy discriminated pho-ton-counting X-ray imager. It must be separate the adsorption coefficient and thickness in order to estimate material distinguish images by using the energy of X-ray adsorbed photons like K-adsorption edge because we can obtain only the amount of adsorption as product of adsorption coefficient and thickness. In X-ray CT, the amount of adsorption is automatically separated to adsorption coefficient and the calculated image of the reconstructed is two dimensions mapping of absorption coefficient. Therefore, it seen that CT is very suitable for energy discriminated X-ray imaging. In the first step of photon -counting X-ray CT, two alkali dry batteries (LR6) were measured and reconstructed image was shown in Fig. 5.

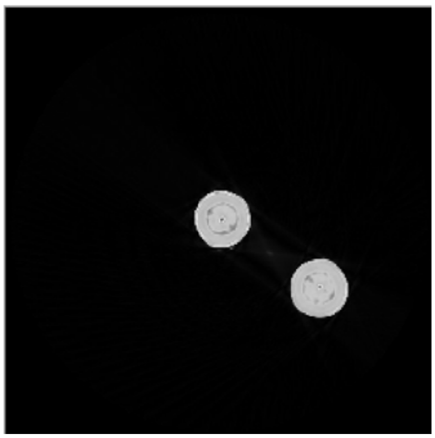

Figure 5: Photon counting X-ray CT image of two alkali dry batteries (LR6).

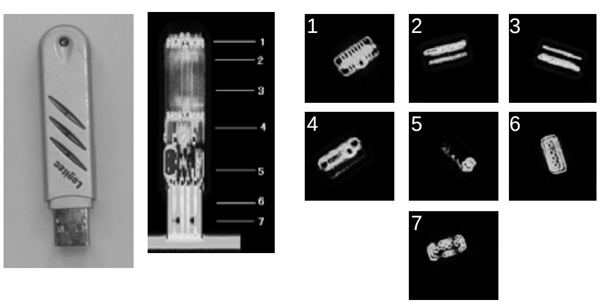

Fig. 6 X-ray CT images of USB-type flash memory device. Left: real image (visible), Center: X-ray penetration image, Right: X-ray cross-sectional images by CT.

In this image reconstruction, we use only "back projection filtered method" that is faithful in the basis of the image reconstruction. In general case, it is thought that a very complex calculation is necessary for the CT image reconstruction. However, it is because the signal from X-ray detector is not stable from difference of X-ray photon energy, beam hardening and Compton scattering. In our case, it was required very simple calculations. This result also has proven higher-linearity of our imager between incident number of photon and out-put. The cross-section photographs of the USB type flash memory are shown in Fig. 6 as one the example of photon counting CT image. This CT image was taken by only 64 pixels detector array, but clear picture was obtained by photon counting X-ray CT. Of course, we can use the USB memory as well as before X-rays is irradiated because the amount of the radiation exposure is small since the photon counting device has good SNR in the low radiation amount region. It is a real nondestructive testing. The other example X-ray CT images of ballpoint pen were shown in Fig. 7.

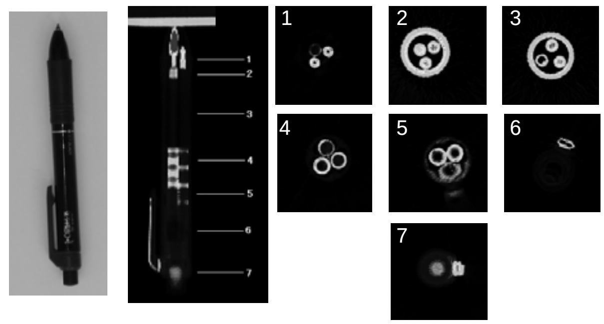

Fig. 7 X-ray CT images of ballpoint pen. Left: real image (visible), Center: X-ray penetration image, Right: X-ray cross-sectional images by CT.

Finally, the atomic number discrimination properties by using dual energy band of X-ray are shown in Fig. 8. The horizontal axis shows the atomic number Z of the materials (original numbers), and the vertical axis shows the measured atomic number by X-ray CT.

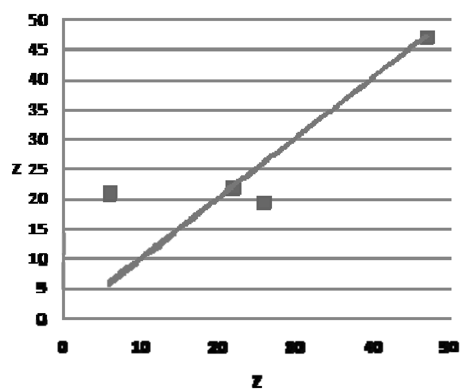

Fig. 8 Atomic number discrimination properties by using dual energy band of X-ray. The horizontal axis shows the original atomic number Z of the materials and the vertical axis shows the measured Z. The plots shows calculated data and the lines shows ideal data.

In the region of high atomic number such as Fe, Cu, Ti, a good linear relation between the original Z and the measured Z. However, in the low atomic number region of carbon, the error margin of measured Z was grown. In this region, the scattered line was not ignore because the hard X-ray source was used for in this experiment.

4. CONCLUSION

The photon counting X-ray imaging, such as X-ray penetration and X-ray CT have become many interesting results like as shown in this paper. It is proven, and there is a result of being possible to find it newly by making the prototype imager though a part of result was forecast. We would like to aim at achieving of the nano-pixel and making of the “Nanovision” of the area of invisibility light by using a new idea in addition to photo counting X-ray imaging device in the future as a Nanovision science that means handling one electron and one photon actually. The discrimination of atomic number of the penetrated materials could be obtained by using this X-ray CT system. An accurate measurement that ascertains the character of X-ray and a new analytical algorithm might be necessary for the accuracy improvement in the future.

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