Combined X-ray CT-SPECT System with a CZT Detector

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ABSTRACT

A single CdZnTe detector is tested for suitability in a prototype CT/ SPECT system designed to acquire both emission and transmission data. The detector has the size of 1×1-cm^2 with 4×4 1.5×1.5mm^2 pixellated anodes. Since the detector is smaller than imaged object, we translated it in an arc centered at the x-ray tube to image larger objects. Pulse counting electronics with very short shaping time (50 ns) are used to satisfy high photon rates in x-ray imaging, and response linearity up to 3×10^5 counts per second per detector element is achieved. The energy resolution of 122-keV gamma-ray is measured to be 14%. We have characterized the system performance by scanning a radiographic resolution phantom and the Hoffman brain phantom. The spatial resolution of CT and SPECT are about 1 mm and 7 mm, respectively.

Keywords: CdZnTe detector, CT and SPECT, radiographic phantom, Hoffman Brain Phantom, spatial resolution

1. INTRODUCTION

During the past several years, position sensitive detectors fabricated from wide bandgap semiconductors have been proposed and fabricated to meet a wide variety of applications. Recent work has used cadmium zinc telluride because of its availability in sizes of 1cm^2 and bulk resistivity reaching $10^{11}\Omega$cm.

Dual-modality systems to combine anatomical CT and functional SPECT images have shown to improve localization and quantitation of radiopharmaceutical uptake [1-3]. These systems have different imaging planes for CT and radionuclide imaging because the scattered x-ray radiation from CT can damage radionuclide detectors, and imaging is performed sequentially by moving a common patient table that can slide into both imaging devices. Ideally, two imaging studies are performed as close in time as possible to reduce potential patient motion and physioanatomical changes (e.g., wash out of CT contrast media). We have tested a prototype CT/SPECT system using a single common detector, which can image the same plane of an object with both modalities.

2. MATERIALS AND METHODS

The dimension of the CdZnTe crystal is $10\times10\times5$ mm^3. The cathode consists of a continuous gold coating of a 10×10 mm^2 surface. The anodes are pixellated to 4×4 with a pixel dimension of 1.5×1.5 mm^2 with interpixel spacing of 0.125 mm and a ring electrode is placed around these pixels as a guard ring. Readout electronics with 50-ns pulse-shaping time were used for this system. The short pulse shaping time enables measurements of relatively high x-ray count rates, and response linearity up to $\sim3\times10^5$ cps was observed. Energy resolution obtained with these electronics was 17 keV (14 %) FWHM for 122-keV gamma rays, which is limited by the very short pulse shaping time of the amplifier.

The x-ray CT is in the third generation fan-beam geometry. Since the detector is smaller than the imaged object, we translate the detector along an arc centered at the focus of the x-ray tube to acquire full projection data. The x-ray tube rotates along with the detector so that a narrow beam follows the detector. To acquire projection data from different angles, the gantry rotates the x-ray tube and the detector around an imaged object, forming a reconstruction circle of 25-cm diameter. To localize radionuclide activities, a collimator is placed in front of the detector. The collimator hole geometry is hexagonal with 30-mm long and 1.5-mm wide.

Two phantoms are imaged in this study to test the performance of our system. The first is a radiographic resolution phantom. It consists of a 127-mm diameter acrylic cylinder with 9 rows of 9 holes drilled. The largest holes have 3.00-mm diameters with 3.00-mm edge-to-edge separation. The subsequent rows have smaller diameters and separation by 0.25-mm increments. This phantom is scanned for x-ray CT with 120 keVp and 2.0 mA tube bias and current. The second is the three-dimensional Hoffman brain phantom. This phantom is filled with aquarious solution of 60-mCi ^{99m}Tc sodium pertechnetate.

For x-ray CT, the projection data are convolved with a Ramachandran-Lakshminarayan [4] kernel and reconstructed onto a 256x256 matrix using a backprojection algorithm developed for the curved detector geometry [4]. This convolution-backprojection algorithm is analogous to the filtered backprojection algorithm. For SPECT, the projection data are reconstructed with a maximum likelihood expectation-maximization(MLEM) algorithm incorporating attenuation correction from the CT image and partial volume effect correction modeling the collimator spatial response function with multiple rays [5].

3. RESULTS

A CT image of the radiographic resolution phantom is shown in Fig. 1. The smallest holes that can be visually separated are the second row holes (1.25-mm diameters). The line profiles of some of the holes from the CT image are shown in Fig. 2, which also shows valleys for the holes down to 1.25 mm.

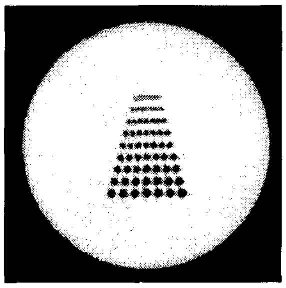

Figure 1: CT image of radiographic resolution phantom. The diameter of the phantom (white disk) is 127 mm. The hole size and the hole separation (edge-to-edge) of the bottom row are 3.00 mm, and these decrease by 0.25-mm increments in subsequent rows.

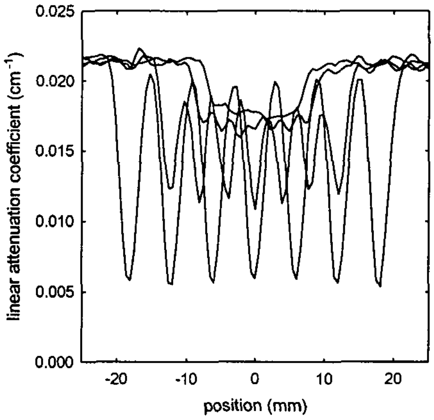

Figure 2: Line profiles of x-ray CT image of a radiographic resolution phantom: (black line) 3.00 mm hole diameter and hole-to-hole separation, (green) 2.00 mm, (blue) 1.25 mm, and (red) 1.00 mm. Resolution limit is about 1.2 mm, also as can be seen from the CT image in Fig. 1.

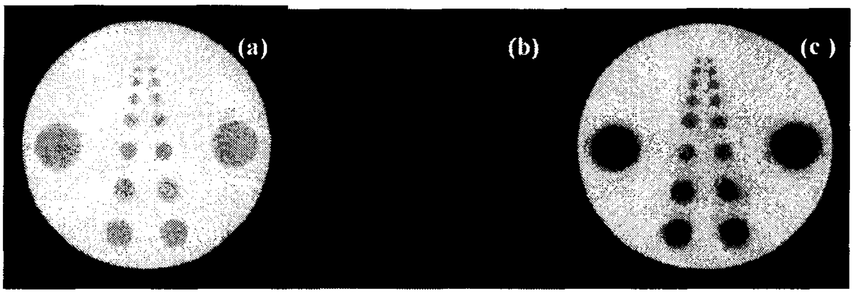

Figure 3: Images of hot rod phantom; (a) X-ray CT image, (b) SPECT image and (c) overlayed CT/SPECT image.

X-ray CT and SPECT images of the Hoffman brain phantom are shown in Fig. 4 (a) and (b), respectively. From some of details visible in the SPECT image, we estimate the spatial resolution of SPECT to be about 7 mm. It is noted that the image registration is intrinsic, since the exactly same geometry is used

for both imaging modalities.

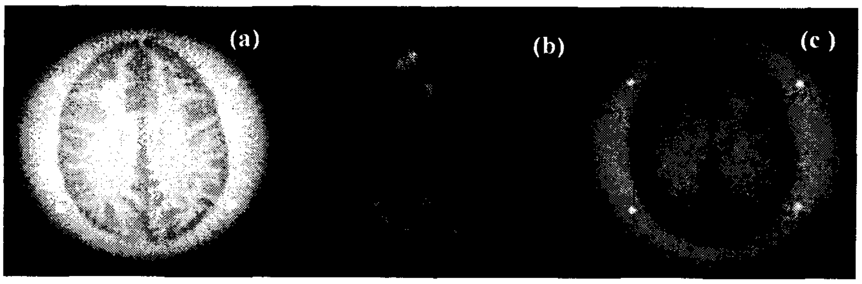

Figure 4: Images of Hoffman Brain Phantom; (a) X-ray CT image, (b) SPECT image and (c) overlayed CT/SPECT image. The phantom is filled with aquarious solution of 60-mCi ^{99m}Tc sodium pertechnetate.

4. DISCUSSIONS AND CONCLUSION

We tested a prototype imaging system capable of performing x-ray CT and SPECT using a single CZT room-temperature semiconductor detector. We measured the x-ray CT spatial resolution to be about 1 mm. The spatial resolution of SPECT is estimated to be around 7 mm. The registration of images from these two modalities is intrinsic since the geometry of imaging is identical.

5. REFERENCES

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