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LSO based dual slice helical CT and PET demonstrators

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ABSTRACT

Two demonstrators, a spiralCT and a miniPET, have been designed and constructed for educational purposes. Computed tomographs (CTs) and positron emission tomographs (PETs) are some of the most commonly used structural and functional imaging devices in medicine, respectively. There is a need for transparent demonstrators where the principles of the different modalities and their functions are presented. The aim of the developments of these systems was to present the major building blocks of CT and PET for undergraduate students. Photon detection in both systems is based on small pixelised scintillation crystals with position sensitive PMT readout. Similar analogue and digital data processing based on FPGA technique is applied for the demonstrators and common image reconstruction and presentation software components are used.

1. Introduction

For its undergraduate courses of Medical Imaging at the Royal Institute of Technology (KTH), several demonstrators of modular and transparent systems have been designed and built to present the function of different imaging modalities [1–3]. Dual energy, dual slice helical CT (called KTH-spiralCT) and a small PET (KTH-miniPET) is a continuation of this tradition to provide tools for laboratory exercise in education.

Both systems are based on small ($2\times2\times10\ mm^3$) LSO crystals. The scintillator light is detected by position sensitive photomultiplier tubes (PSPMTs) connected to FPGA based digital data acquisition systems. Unified data acquisition electronics and software platform were developed to serve the modularity and transparency of the systems. Both demonstrators were built using a similar type of gantry with computer controlled stepper motors for moving the detectors and the phantom.

2. KTH-CT setup

The principles of the KTH-spiralCT (Fig. 1) are the same as that of third generation multislice CT scanners, but some compromises were made in the construction of the demonstrator. In the third generation CT scanners the detector and the X-ray tube rotate around the patient. To achieve simple mechanical design for the KTH-spiralCT the phantom is rotated between the stationary detector and the photon source.

Instead of an X-ray tube, a 10 mCi ^{241}Am low energy gamma-ray source is used to simplify the operation of the KTH-spiralCT. The source is placed in a tungsten collimator and the cone shaped beam diameter is 5 cm at the detector surface.

The photon detector of the CT demonstrator was built using 48 LSO scintillators placed in two rows and optically coupled to a Hamamatsu PSPMT. Since the number of photons reaching the detector from the ^{241}Am source is several orders of magnitude lower than from an X-ray tube, single photon counting and energy analysis could be made. However, due to the poor energy resolution of the crystals and the PSPMT the peaks at low energies are superposed; thus only the groups of low and high energy photons are distinguishable. The two most intensive energy peaks around 17.8 and 59.5 keV were used simultaneously to acquire images in two energy regions. The main differences between a 3rd generation CT scanner and the KTH-spiralCT are summarized in Table 1.

3. KTH-miniPET setup

The KTH-miniPET scanner contains two stationary detector modules placed on both sides of the rotating phantom. In the head of the plastic doll phantom positron emitting ^{22}Na radiation sources are hidden. The annihilation photons are detected by the two opposite detector modules, each assembled of 64 LSO crystals in an 8×8 configuration array and the scintillation light is registered by a PSPMT. The KTH-miniPET is built with the same

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Fig. 1. Photo of KTH-spiralCT. The ^{241}Am source is in left and the detector is visible behind the doll on the right.

Table 1
Main differences between third generation CT scanners and the KTH-spiralCT.

	Third generation CT	KTH-spiralCT
Source	X-ray tube	^{241}Am source
Detector	Multiple layers of semiconductor	Pixelated LSO crystals with PSPMT
Detection	Photon intensity is measured	Photon counting in a predefined energy window
Mechanics	Detectors and source rotates around the patient	Phantom rotates between the source and detector

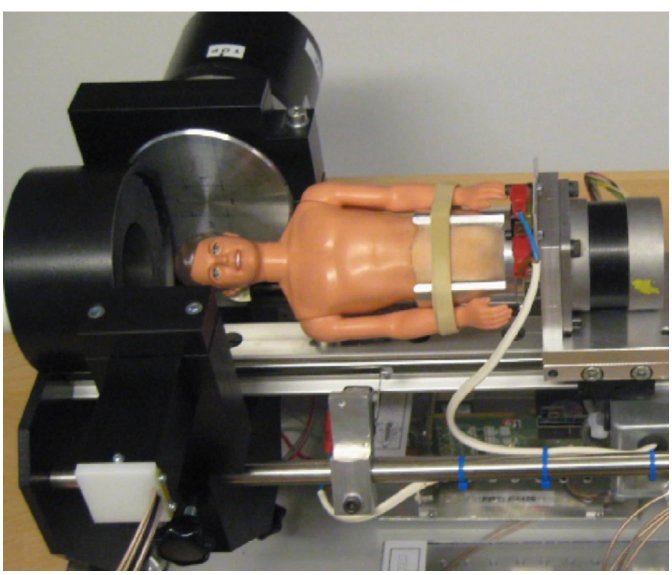

Fig. 2. Photo of KTH-miniPET. Two detectors (black tubes) on both side of the phantom are on the top and bottom. ^{22}Na sources are in the doll's head.

type of gantry used as in KTH-spiralCT. The photo of the demonstrator is shown in Fig. 2.

4. Data acquisition electronics

In both demonstrators the same types of data acquisition cards (DAQ) are used [4]. The DAQ consists of the analogue front end electronics and the digital front end electronics (DFEE) modules. The DFEE is based on a Memec mini-module with a Xilinx Virtex-4 FPGA and an ethernet interface. The analogue corner signals of the PSPMT are digitized using a 12 bit, 50 MHz, 4channel ADC. The digital signal processor core in the FPGA determines the energy and the *X*, *Y* coordinates of the incoming photons and generates a time stamp for each event. These parameters are transferred to the data acquisition computer via 100 Mbit ethernet network. Data are acquired in list mode; therefore, full post-processing of the data (such as energy and position discrimination) is performed in the PC.

5. Data acquisition, image reconstruction and presentation software

Both demonstrators use the same software components, such as DAQ and stepper motor controlling, image reconstruction and image presentation. Position and energy discriminations of the incoming events are also performed in the data acquisition PC. Coincidence sorting with different time windows in KTH-miniPET and sinogram generation in both demonstrators are performed in the data acquisition program. Filtered back projection [5] and the iterative ML-EM [6] methods have been implemented for the demonstration of the quality and performance of the different image reconstruction algorithms.

Low and high energy cross-sectional reconstructed slices of a Barbie doll acquired by the KTH-spiralCT are shown in Fig. 3. Reconstruction of the two ^{22}Na point sources inside the doll's head is shown in Fig. 4. One of the tasks during the laboratory exercise is to determine the size, distance and location of the sources in the head. Further task is to estimate the optimal reconstruction parameters.

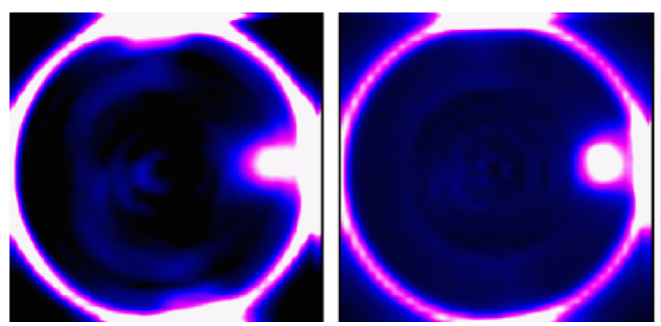

Fig. 3. ML-EM CT reconstruction of the doll. Low and high energy cross-sectional slices are shown in left and right, respectively. The white spot shows the position of the steel bullet.

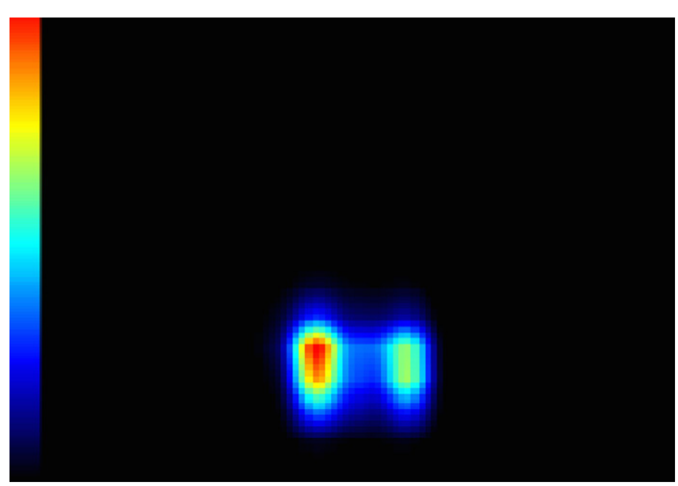

Fig. 4. ML-EM PET reconstruction of the two ^{22}Na point sources using 20 iterations.

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6. Conclusion

To make CT and PET imaging more attractive for students in the laboratory exercise, two dolls, Barbie and Ken, are imaged. They are made of plastic that has suitable absorption in the considered energy range, and are light and rigid enough to be mounted in both the KTH-spiralCT and the KTH-miniPET.

To demonstrate the imaging capacity in terms of contrast and spatial resolution in the KTH-spiralCT, a steel bullet, with 6 mm diameter, has been attached to the back of Barbie. To study the influence of photon energy on contrast level of the image, reconstructions are made from data acquired at different energies. The steps of the data acquisition are similar to those of the conventional CT scanners; the first step is the collection of a topogram where the students select the region where the bullet is located, the second step is the tomographical acquisition and then image reconstruction using different parameters.

To demonstrate the principles of PET, as mentioned above, ^{22}Na point sources are placed in Ken's head. Students can find the location of the sources and determine their distance.

The demonstrators are fully transparent; the detectors, the data acquisition electronics, the data collection, the signal and image processing and the reconstruction steps are separated to serve the understanding of the basics of CT and PET imaging.

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