A High-Resolution PET Detector For Preclinical Imaging Applications

Abdullah A. Refeay[1] and Ramsey D. Badawi[1,2]

[1] UC Davis Medical Center, Radiology, Sacramento, California, United States of America

[2] UC Davis, Biomedical Engineering, Davis, California, United States of America

Introduction

PET scanner performance depends on the task at hand, and there is no single scanner or detector geometry that is optimal for all imaging tasks – for example intra-operative PET for humans requires very different arrangements to that needed for imaging rodent brains. Our work in our PET instrumentation lab is to develop the components needed for a flexible, modular, and scalable PET toolkit that can be easily configured for optimal performance in a wide range of imaging tasks. In the proposed system, the PET detector is equipped with ultra-high resolution scintillation crystals, very small Silicon Photomultipliers (SiPM) for measuring scintillation light, a state-of-art front-end electronics scheme, and a built-in data acquisition (DAQ) unit.

Design/Method

In this project, we are working towards a PET detector with 0.5x0.5x12 mm^3 crystals for ultra-high spatial resolution. A possible application geometry for such detectors is shown in Fig. 1.

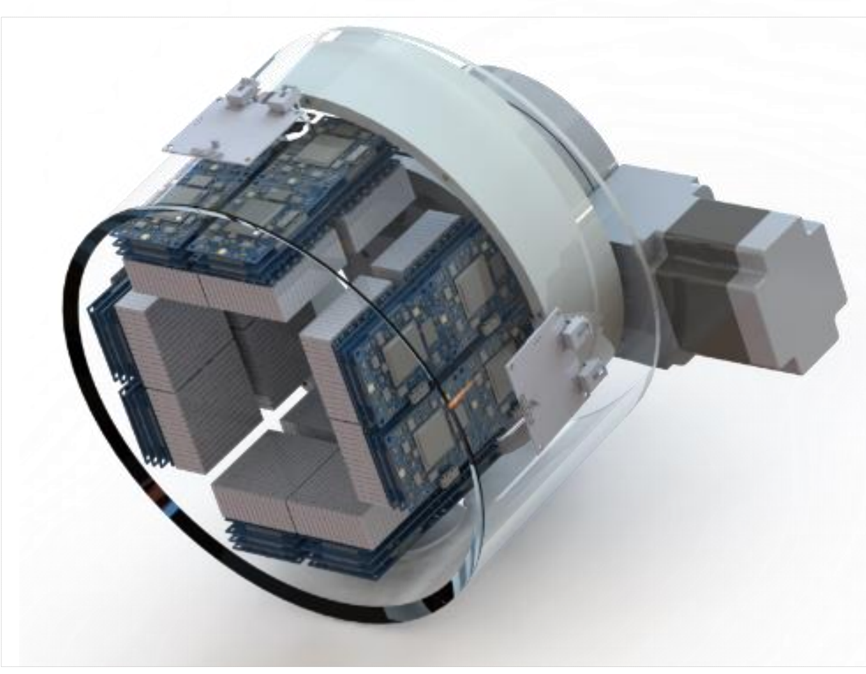

Fig.1. CAD design of the Proposed high-resolution PET scanner.

For prototyping purposes, we start by working with an 8x8 array of LSO scintillator with crystal dimension 1.2x1.2x12 mm^3 is used to absorb and detect the annihilation gammas. We use an 8x8 array of 1x1mm^2 KETEK SiPMs for detecting the scintillation light. A 1mm acrylic light guide and Saint-Gobian BC-631 grease used for LSO-SiPM optical coupling. We developed customized FPGA-based readout electronics for signal processing and data acquisition. All these components are intended to be stacked into a single modular design as shown in Figure 2. The analog circuit requires reading out 64 analog channels, a DPC (Discretized Positioning Circuit) multiplexing scheme is implemented to multiplex the 64 analog channels into 4 channels. The multiplexed four signals are digitized using Sigma-Delta ADC that is implemented on the economic Xilinx FPGA chip (XC7A35T). The design is flexible enough to accommodate common PET pulse widths. Data analysis includes generating a 2D crystal position map (flood histogram) and estimating the energy resolution (ER) for each LSO crystal.

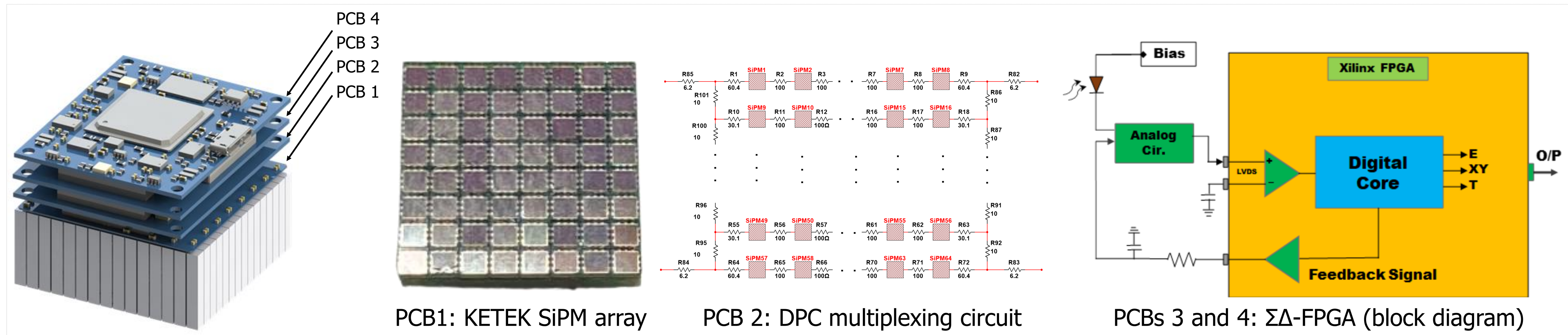

Fig.2. Left: Modular PET detector, PCB1: KETEK SiPMs array, PCB2: DPC multiplexing circuit, PCB 3&4: ΣΔ-FPGA block diagram.

Results

The data are reconstructed in the form of flood histogram as shown in figure 3. Each crystal is analyzed based on the crystal-crystal distance, peak comparison, and the energy resolution of each peak. The energy spectra of the individual crystals are back-ground subtracted. The preliminary data showed that the average energy resolution of 10.66% ± 0.96% at 511 keV photopeak of ^{22}Na is achieved (figure 3). For crystal identification, all the 64 crystals of LSO array are resolved and identified. The central crystals accumulate more counts and give better energy resolution as shown in the color-coded histograms. As the pitch size is ~1.2mm in LSO-SiPM combination with 8x8 elements in both arrays (thus it is 1:1 readout), the side and edge crystals show good energy profiles as shown in XY-position profiles in figure 3. To analyze the flood map, a clustering algorithm is used to draw boundaries over the peak position of each crystal extracting different parameters such as peak position, counts, area, FWHM, and peak distance; the min, average, and max of some of these parameters are included on table 1.

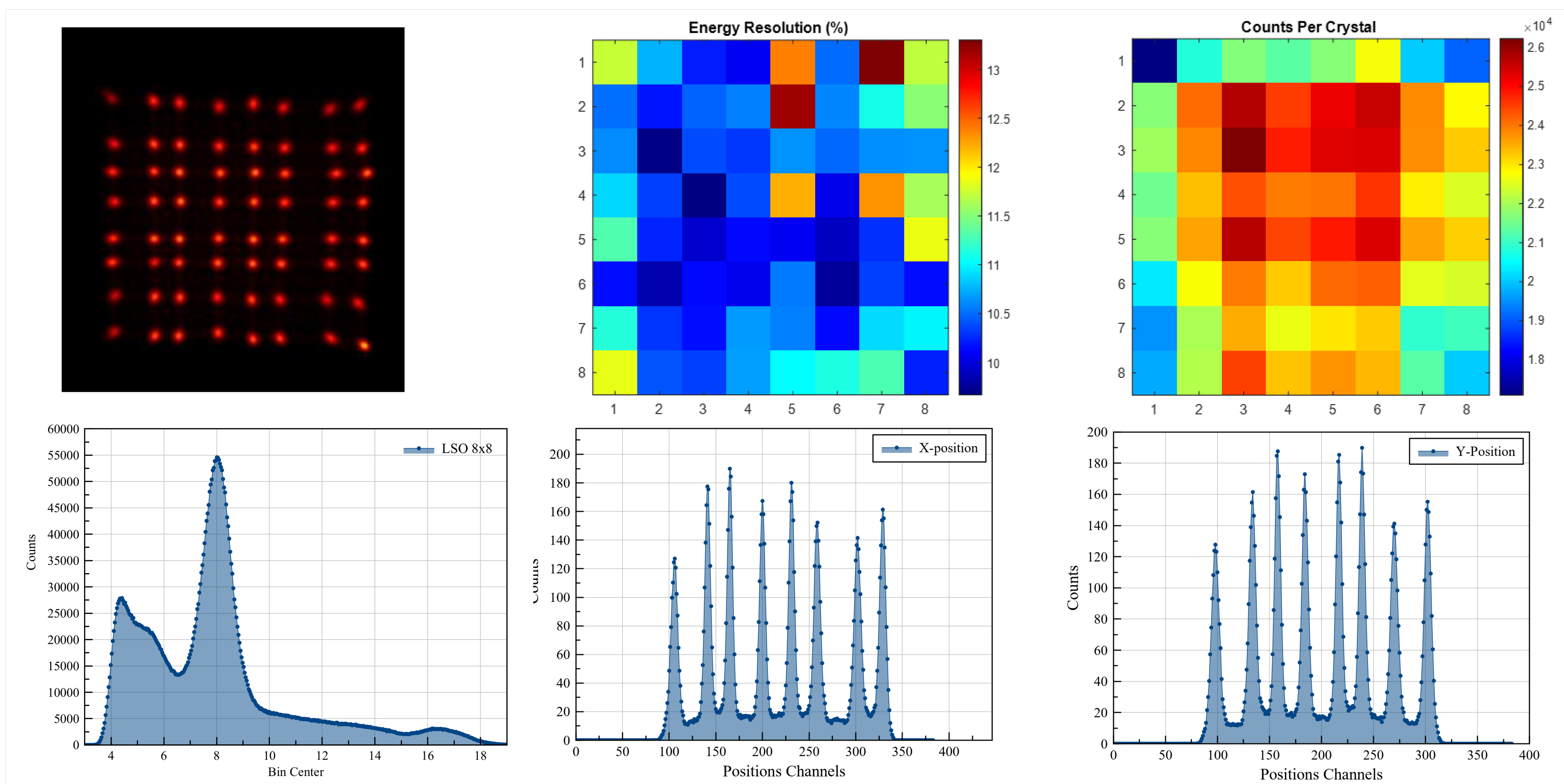

Fig.3. Top: Flood histogram map of PET detector (Left), color-coded map for energy resolution (Middle) and counts (Right) per crystal. Bottom: Energy resolution histogram for the array (Left), X-position profile (Middle), and Y-position profile (Right).

Crystal Parameter	Min	Average	Max
Number of Counts	18620	24654	30687
Energy Resolution	9.67%	10.66%	13.3%
Flood Peak Distance	0.8297	1.284	1.738
FWHM/Distance	3.155	4.025	4.894
Peak Position	6.8	7.463	8.481

Table 1. Parameters generated from flood map analysis

Conclusions

A prototype PET detector module equipped with state-of-art technology is being developed. Various experiments have been performed in testing and validation. The final module will be characterized based on depth of interaction (DOI) estimation, intrinsic spatial resolution, timing resolution, and estimation of the count rate performance, The module under development is intended to serve for ultra-high spatial resolution preclinical application such as the rodent brain, the human brain, the human breast and/or wrist.