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Performance Evaluation of a new Digital Brain PET based on the Plug&Imaging Sensor Technology

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Introduction

Positron Emission Tomography (PET) is a 3D-imaging technique able to obtain functional information of biodynamic processes from living tissues and PET exams have become a widespread diagnosis instrument for many metabolic disorders. The challenging limits of PET analysis are low sensitivity and poor spatial resolution when applied for brain investigations, because of ill-fitting geometry coverage of the head and analogical electronics readout that reduces the data acquisition rate.

In this work it is described a novel **Digital Brain PET** prototype we assembled using the **Plug&Imaging** (P&I) sensor technology with a focus on the evaluation methods and the results of its performances. The peculiar advantages of P&I is the miniaturization of sensitive elements and the fast electronics readout. The former allows high solid angle coverage, the latter enables a signal digitization free of significant fractional dead time, favoring the acquisition of huge datastreams even from low radioactivity inlets. Despite of conventional PET systems, the P&I allows to record all prompts widening the margins of image optimization. The brain PET scanner performances were evaluated according to the NEMA standard protocols. **Noise Equivalent Count Rate** (NECR), **Sensitivity** and **Spatial Resolution** were computed. The P&I technology allows to reach highly competitive performances compared to the conventional digital brain-scanners.

Materials and Methods

P&I and digital brain PET prototype

A *P&I* unit is composed of a pulse generator head and a printed circuit board (PCB) that provides the bias voltage. One head consists in a 6×6 LYSO scintillator array read by a 6×6 SiPM array in a 1:1 coupling configuration (Fig.1a). The LYSO matrix contains 3.9×3.9×20 mm^3 crystals. One PCB serves 72 LYSO/SiPM channels and provides the MVT logic that consists in two FPGA-only channels with 4 LVDS comparators imposing 4 reference voltages. When a PET event pulse is generated by a SiPM, it is split in 4 signals that are sent to a LVDS. The output communicates with two TDCs for determining the signal transitions, therefore the system records a total of 8 sample per pulse. The sampled pulse is packed in a event-word and stored in a FIFO, then data are sent to the acquisition server via 10Gbit Ethernet interface.

The *digital brain-PET prototype* is a scanner composed of 44 functional sectors arranged in a cylindrical shape (Fig.1c). Each sector contains 4 PCBs serving 8 P\&I heads extending the total scanner axial length (Fig.1b). The scanner diameter measures 375 mm wile the axial length, that coincides with the longitudinal FOV, measures 201.6 mm. The transverse FOV is 218 mm. Globally, there are 48 detector rings composing the scanner and 264 LYSO/SiPM channels per ring.

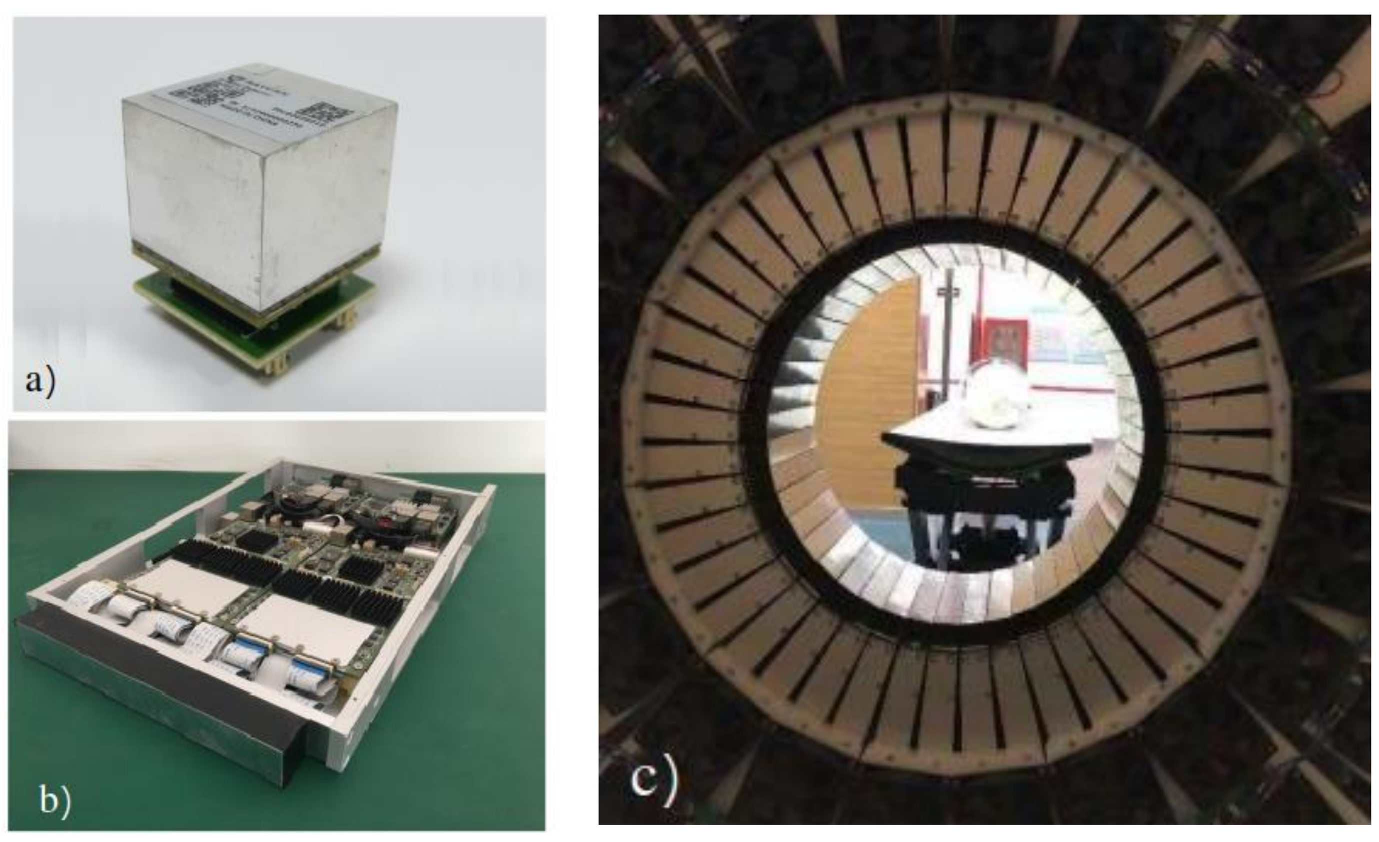

Fig. 1. a) A 12.7 cm^3 LYSO/SiPM detector unit ; b) Scanner sector: packing of 8 heads controlled by 4 MVT boards; c) The brain-PET scanner is composed by 44 sectors radially arranged in a cylindrical shape.

Data Processing

All the signals with a voltage amplitude high enough to cross all the thresholds (10, 60, 110, 160 mV) are acquired as prompts. Fitting the 8 time-voltage points per prompt with an exponential waveform, we retrieve the released energy spectrum. Every 2 prompts depositing energy within 2σ around the photoelectric peak and detected within 2 ns are considered coincidences. Coincidences are organized into sinograms. For image reconstruction we used 3DOSEM/PSF algorithm (Fig.2d).

Performance Evaluation

Count-rate: we used a HDPE (ρ= 0.96 g/cm^3) cylindrical human phantom of 700 mm axial length, 202 mm diameter and 22421.8 mL volume. Set 45 mm far from its base centre, a 3.2 mm diameter hole allows the FDG radionuclide injection, with a 15 mCi activity all along the cylinder length. The phantom was placed in order to have one face at the beginning of the axial FOV. We took acquisitions for 8 hours, 20 minutes each. We computed the rate of Total, True, Scatter and Random coincidences, the Scatter Fraction (SF) and the Noise Equivalent Count Rate (NECR).

Sensitivity: a ^{22}Na point source of 30 µCi activity was positioned at the centre of the FOV and then moved on both sides along the axial direction by 5 mm steps to cover a total distance of 200 mm. We took acquisitions of 5 minutes each.

Spatial Resolution a ^{22}Na point source of 30 µCi activity was positioned at the FOV centre and then moved radially on different positions. Measures were also repeated shifting the source 50 mm axially. We took acquisitions of 5 minutes each. We computed the FWHM of axial, tangential and radial profiles from reconstructed images.

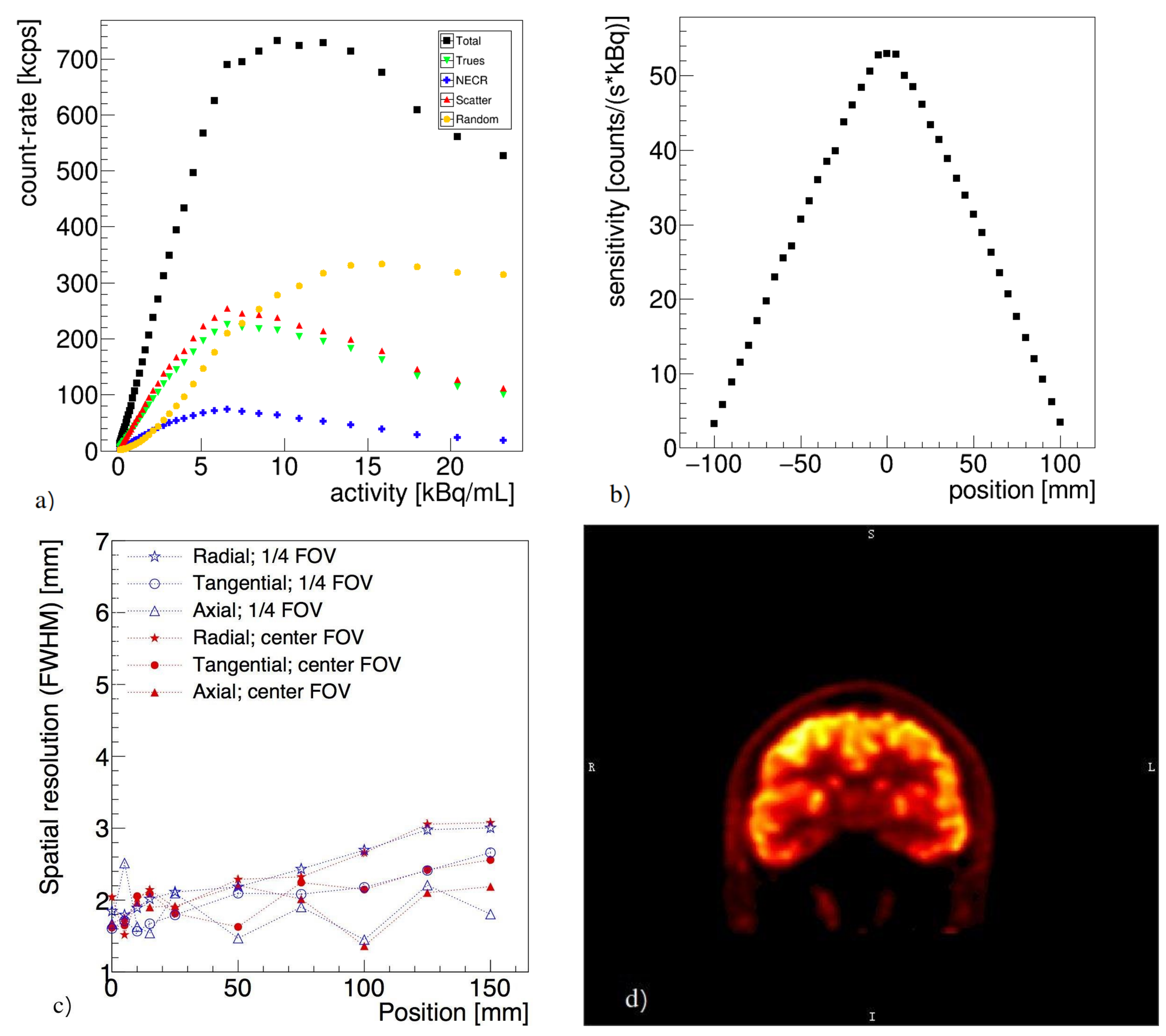

Fig. 2. a) Count-rate profile of human scatter phantom: true count rate (green) and NECR (blue); b) Sensitivity: peak value 5.84% around the FOV centre; c) Spatial resolution at FOV centre and 1/4 FOV: max value 1.8 mm; d) Brain image reconstruction with 3DOSEM/PSF algorithm.

Results and Conclusions

Count-rate experiment shows (Fig.2a) a maximal NECR of 73 kcps for a 6.57 kBq/mL activity. The SF values is 53.12%. The *Sensitivity* profile (Fig.2b) indicates that the peak value is 52.94 cps/kBq (5.84% absolute sensitivity) in a 20 mm interval around the FOV centre. The *Spatial Resolution* profile (Fig.3a) shows a constant axial value of 1.8 mm at different radial spots. Both radial and tangential resolution are around 1.8 mm on the longitudinal axis, while degrade towards the scanner edges.

We have seen how the MVT fast readout method increases the count rate performances and the NECR peak even with low activity. Compared to the current PET systems, the prompts readout rate is 2-3 times higher with MVT technology reaching around 100 Mcps. Moreover the recorded sensitivity and spatial resolution make this system highly competitive with the state-of-the-art PET machines. In further analysis we aim to perform DOI corrections to improve spatial resolution.

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