Monte Carlo evaluation of a Total-Body Rat preclinical scanner based on AI enhanced BGO detectors

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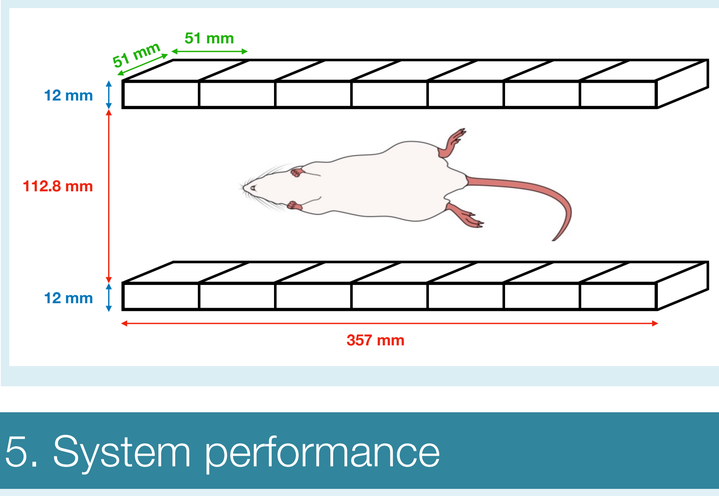
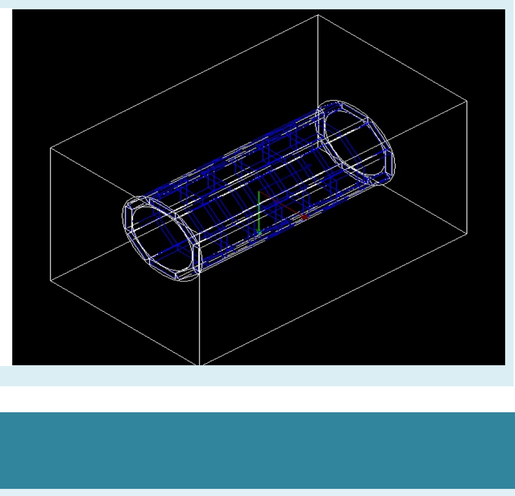
1. Aim

We developed a Total-Body Rat preclinical scanner with an axial field of view of 357 mm. The PET modules are based on BGO detectors and the position of the event as well as the correspondent timestamp are obtained with the use of a neural network [1,2]. The aim is to combine both the state-of-the-art detector parameters and the excellent sensibility given by the long axial coverage in order to obtain good performance in terms of image quality.

2. Scanner design

The proposed scanner has a diameter of 112.8 mm and axial FOV of 357 mm which is able to cover the whole body rat.
The scanner architecture is composed of 7 rings each of which has 8 monolithic detectors. Each detector consists of a 51x51x12 mm^3 BGO crystal read by 64-channel matrix of 6 mm pitch Hamamatsu multi pixel photon counters (MPPCs, S14160-6050), read-out by a custom-made acquisition electronics based on the HRFlexToT ASIC.





3. Monte Carlo simulation

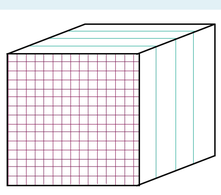
The simulations have been performed using GATE software [3]. In this context, several parameters obtained through experimental detector characterisation of UTOFPET detector [1, 2, 5] have been included such as energy resolution (20.2%) and temporal resolution (300 ps).
Once obtained the raw data from simulation, we applied a space-variant gaussian smearing to the event position inside the crystal in order to model the intrinsic spatial resolution of the detector of 1.1 mm FWHM (X,Y) and 1.8 mm FWHM (DOI).
After the smearing step, we segmented the monolithic block into virtual crystals, leading us to 4 DOI layers each of one composed by 625 crystals.

4. Image reconstruction

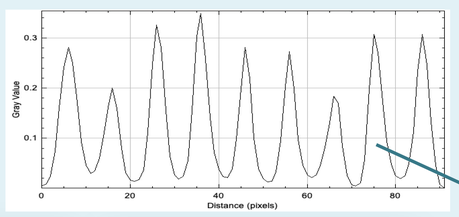
We used a proprietary reconstruction software developed in-house [6] that processes raw data in histogram mode. The algorithm is based on MLEM + PSF reconstruction.
The virtual pixel size of 2.04x2.04x3 mm^3 leads to $6x10^6$ LORs for 2 opposite modules and the choice of the virtual pixels dimension is limited by the memory needed to store the histogram. In order to reduce the histogram size, a 1 vs 5 coincidence scheme has been used.
At this time, the histogram weights about 16 Gb and the reconstruction takes about 200 seconds for iteration.
The convergence (i.e, the stability of Recovery Coefficient) is reached at about the 100^{th} iteration.

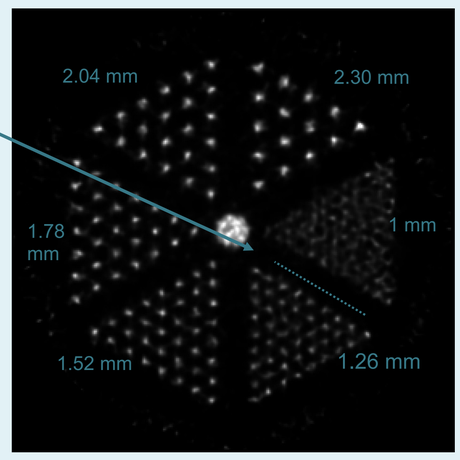
5. System performance

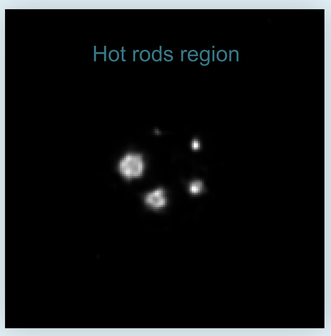
The system performance have been evaluated following NEMA NU4-2008 standards [4]. The scanner provides a peak of sensitivity of 31.9% (EW = 350-650 keV) and a NECR peak of 717 kcps at 14 MBq. For spatial resolution, a Derenzo phantom have been simulated: the activity was 100 MBq and the dimensions of the rods ranged from 1 mm to 2.3 mm at step of 0.22 mm.

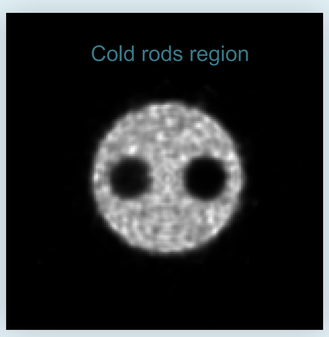


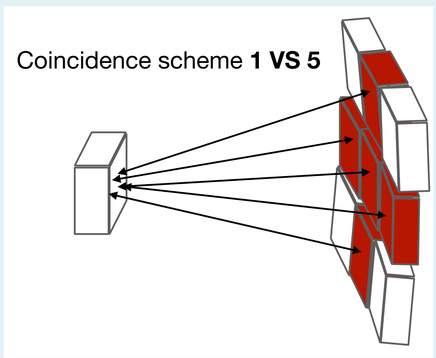
BGO CRYSTAL
Matrix of 25x25 virtual pixels and 4 virtual layers for DOI encoding











Sensitivity [NO EW]	43.517%
Sensitivity [250-750 keV]	32.494%
Sensitivity [350-650 keV]	31.852%
NECR peak value [kcps]	716.996
NECR peak position [MBq]	14

Diameter [mm]	**5**	**4**	**3**	**2**	**1**
RC	0.99	0.93	0.86	0.82	0.28

Material	**Water**	**Air**
SOR	0.051	0.001

6. Conclusions

- The proposed scanner can be used to perform total body rat imaging without any bed motions
- Exploiting the state-of-the-art positioning events algorithm on BGO crystals, it is possible to obtain state-of-the-art results in terms of sensibility and NECR curve.
- The results shown can still be improved as the full sensitivity of the scanner is not exploited

7. Future work

- Implement a larger coincidence scheme to exploit the full sensibility of the scanner
- Perform simulation with anatomical rat phantoms
- Perform dynamic imaging simulations defining sequences of short dynamic frames

8. References

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