DEVELOPMENTS IN TOTAL BODY PET SYSTEMS

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HARDWARE DETECTOR AND SYSTEM DEVELOPMENT IN MEDISIP

• MEDISIP software experience
  • Iterative reconstruction
  • System design with Monte Carlo simulations

• Infinity lab
  • Direct access to phantom animal and tracer
  • Strengths and limitations of current imaging systems

• MEDISIP high res detectors
  • Electronics
  • Silicon photomultipliers
  • Positioning algorithms
  • Collimator production

• MEDISIP systems
  • High resolution detectors
  • Compact design
  • Iterative reconstruction

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MICRO PET DEVELOPMENT IN GHENT

2014
DigiPET v1

2015
DigiPET v2

2016
Beta Cube v1

2017
Molecubes Beta + X Cube

- 8 mm thick LYSO
- 13 cm axial FOV
- still sub mm

FIRST PET-CT installed in February 2017
TOTAL BODY PET CONCEPT

From current 15-25 cm to 1-2 m long PET

Point peak Sensitivity: 4-6%
Point peak Sensitivity: 12-24%

Body imaging sensitivity (NECR): 7-21 cps/kBq
Body imaging sensitivity (NECR): 200-500 cps/kBq

Acquisition time for total body: 20 min
Acquisition time for total body: 0.5 min

Courtesy of Simon Cherry

Options

Improved images (reduce Poisson noise)
Dynamic imaging (multiple images after each other)
Reduce dose to patients and cost of tracer production
Faster imaging more patients on same day

NEW
NEXT STEPS: TOF, SPATIAL RESOLUTION AND DOI

Improve effective sensitivity by better TOF

PennPET Explorer
250 ps

Siemens Biograph Vision
214 ps

Towards the 2mm limit of spatial resolution in clinical PET

Full body coverage → geometric sensitivity maximal
About 400 ps TOF
2.8 mm crystals
no DOI

Transverse and axial DOI in TB-PET

The promise of nuclear medicine technology: Status and future perspective of high-resolution whole-body PET, Physica Medica, Klaus P. Schäfers
**Medical cyclotron map**
Europe

**Belgium = heart of Europe**

**Unique HR PET tech in Ghent**

**PET 2020**
**EUROPEAN EXPLORER IN GHENT**

Current PET/CT scan

High spatial resolution

Total Body Pet/CT-scan

Slides courtesy of Stefaan Vandenberghe, Boudewijn Brans, Simon Cherry, Joel Karp
Detector
- Monolithic 16 mm thick LYSO
- Readout by analog SiPMs
- Detectors have sub mm intrinsic spatial resolution
- Light sharing + fine sampling + Advanced positioning
  6 layer DOI
- Cost effective base geometry
  70 cm long - 70 cm bore

System performance
- 2-2.5 mm system spatial resolution over whole FOV
- 3-4 times faster for single organ imaging
- 9-10 x faster for routine clinical FDG body PET imaging

Submitted to PMB, Mariele Stockhoff, PhD Ugent
MATERIALS AND METHODS

Optical Simulation
- Gate Monte Carlo Simulation
- Validated LUT Davis reflection model

Detector Calibration

Positioning
- k- Nearest Neighbors
  \[
  \text{Distance}_k = \frac{\sum_{i \in \text{calibrated}} \left( \text{scaledCharge}_{i,k} - \text{calibrated scaledCharge}_{j,k} \right)^2}{\text{DET}}
  \]

Performance evaluation
- Investigated parameters
  - Pixel Size
  - Photon Detection Efficiency (PDE)
  - Reduction of readout channels (Multiplexing*)


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Optical simulation of a monolithic LYSO scintillation crystal coupled to an array of SiPMs.
RESULTS

Spatial resolution in the center

*combined channels (multiplexed)
Whole detector resolution

Small degradation at edges

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DOI resolution: real DOI dependent on the determined depth layer

Layer | Layer Accuracy [%] | Mean absolute error [mm]
--- | --- | ---
1 | 96.6 | 0.99
2 | 70.7 | 1.18
3 | 66.4 | 1.58
4 | 58.4 | 1.91
5 | 50.7 | 2.3
6 | 54.6 | 3.0
**Overall** | **72.2** | **1.6**
Degradation factors:
- Non-Perfect calibration beam
- Lu176 background

USE SIMULATION DATA FOR POSITIONING
- Precise optical reflection model
- Much simpler geometry to simulate than pixelated detectors

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GE discovery MI 4-ring- 20 cm

Pixelated
25 mm thick LYSO
20 cm long - 85 cm bore
13 Liter-94 kg LYSO

0.5 m² SiPM

PET-2020

Monolithic
16 mm thick LYSO
70 cm long - 70 cm bore
25 Liter-180 kg LYSO *

1.5 m² SiPM

Explorer

Pixelated
18 mm thick LYSO
198 cm long – 78.6 cm bore
88 Liter-624 kg LYSO

5 m² SiPM **
ACOLINEARITY DOMINATES CLINICAL PET IN THE LIMIT

PET system resolution for monolithic detectors with 0.7 mm spatial resolution

- N-13
- C-11
- F-18
- no positron range

System radius (mm) vs. PET resolution (FWHM - mm)
ONE RING IS/ARE TWO SEMI-RINGS BY AXIAL SPLITTING
Adaptive per ring based on one motor and camera aperture principle

Compact, Routine mode:
- High sensitivity single organ imaging
- Fast continuous static body scans
- Easier access
- Speed vs. 20 cm
- 9-10x faster (for body imaging)
- 3-4 for single organ imaging
- Spatial resolution of 2 mm with monolithic

Large, Research mode:
- Total body imaging
- Fast continuous body scans
- Long axial FOV
- Speed vs. 20 cm
- 9-10x faster (for body imaging)
- Spatial resolution of 2 mm with monolithic

Adaptive mode:
- Full radially inwards movement of detectors
- 0-50% gaps

Pediatric mode:
- No gaps

Paediatric mode:
- Total body imaging of small object (pediatric)
- Fast dynamic scans
- Speed vs. 20 cm
- 30-40x faster (for body imaging)
- High spatial resolution with 1 mm monolithic
  - 6 layer DOI
  - < 1.5 mm

Adaptive to patient body:
- Fast dynamic body scans
- Brain body interactions
- Speed vs. 20 cm
- 15-25x faster (for body imaging)
- High spatial resolution with 1 mm monolithic
  - 6 layer DOI
  - -> < 1.5 mm
ADAPTIVE APERTURE PET

One PET fits all.

Total body PET2000 GENT UNIVERSITY

Small bore?

Please, no CAT scan again

Hypothyroid in cats

I better fit in here!

Lion Columbus zoo, Ohio imaging center, refurbished
GE LightSpeed 16-slice CAT scanner

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PET2020 IS VERY STRONG COST-EFFECTIVE COMBO

3D detector

Compact parallel computing

Simple Adaptive Mechanical design

Monolithic detectors with light spreading and ML positioning

Gamma photon

Monolithic scintillator

High sampled readout

Real time positioning

3D listmode

TOF acquisition and reconstruction

University of Pisa

https://www.labworld.it/utofpet-sviluppera-nuove-tecnologie-per-rivelatori-pet/
DEEP LEARNING (WELL DEFINED TASKS) AT DIFFERENT LEVELS

ACQUISITION

LOW NOISE RECONSTRUCTION

SYSTEM DESIGN

Sparse total body PET

fwo

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SUMMARY

1. High resolution detectors (sub mm intrinsic) are the basis of this innovative Total Body system
2. Unique high resolution (2 mm system limit)
3. Optimal length for routine PET imaging (90 % of studies are FDG body)
4. Fast throughput for routine imaging
5. Adapts in a simple mechanic transformation to smaller or longer objects
6. Cost-effective (only 2-3 x detector material of current PET-CT)
7. Adapts to a wide range of subjects-One PET fits all
   - axially: standard 70 up to 140 cm axial length
   - transverse to subjects of 35 to 70 cm diameter

Future projects
   - In-beam imaging
   - Lifetime Positronium imaging
TOTAL BODY PET 2020: FIRST ANNOUNCEMENT

Total Body PET 2020
Edinburgh (ed-in-bruh)
June 2020
Thank You!

INTERESTED IN COST EFFECTIVE TOTAL BODY PET

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