Simulating Multi Pixel Detectors for Advanced Radiation Monitoring

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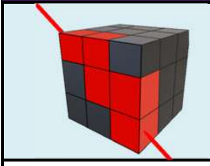


- This study investigates how the geometry of multi-pixel detectors (MPDs) affects performance in environmental radiation monitoring.
- Cubic and non-cubic arrays were modeled and evaluated through testing of hit distribution, angular uniformity, angular sensitivity, and energy uniformity.
- The findings show that regular cubic arrays provide the most reliable balance between angular coverage and ease of manufacture.
- Non-cubic geometries add complexity without delivering meaningful performance gains.

Multi-Pixel Detectors

Single-pixel detectors are widely used in **environmental radiation detection** today. MPDs offer:

- Faster localisation
- More accurate directional reconstruction
- Real-time localisaton

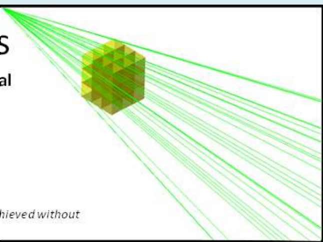
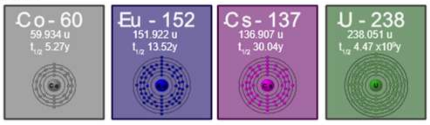


Figure 1. Multipixel detector simulated in Geant4, where localisation can be achieved without movement

Simulation setup

Geant4 was the package used to simulate radioactive decay of particles (Figure 2). The radioactive sources used were:



All sources were placed 20 cm away from the **perimeter** of the detector to **minimise** coincidence summing.

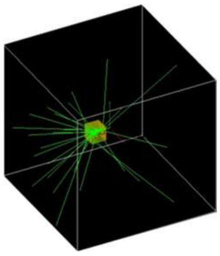


Figure 2. Initial Geant4 setup. 10 cm x 10 cm x 10 cm NaI detector (yellow), lead shielding (red). 100 simulated radiation events visualised within the detector (green).

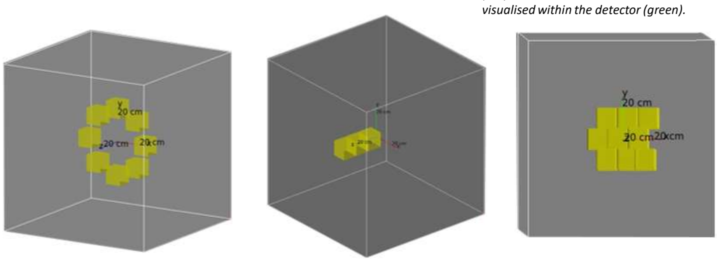


Figure 3. Detector geometry examples – Circular geometry, 3-pixel cubic, and Brick-Bond geometry

Data collection

Three comparative tools were used to analyse how the MPD performed. Geometry performance, angular performance, and quality performance.

<u>Objectives:</u>

- ❖ How do MPDs **differ** from Single-pixel detectors
- ❖ What are the **advantages** of cubic arrays
- ❖ What are the **advantages** of novel arrays
- ❖ How does the **source placement** impact fidelity
- ❖ Investigating **spectral qualities** of MPDs

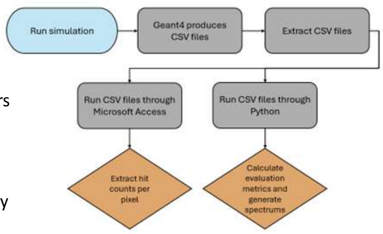


Figure 4. Flowchart illustrating the process from simulation execution through data processing to final evaluation

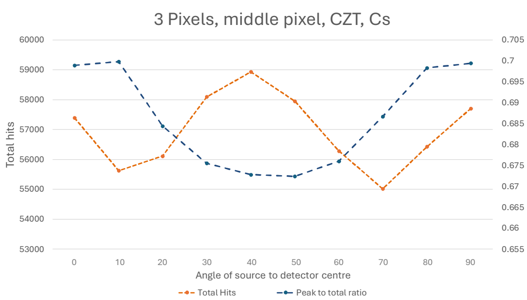


Figure 5. Linearity testing of the three-pixel array across a quarter-arc around the central pixel. At 45º, the increased path length magnifies the solid-angle effect, whereas at 10º and 70º, shorter path lengths reduce this effect.

Experimental validation

- ❖ A Kinova Gen3 robot arm (Figure 6) was used to hold a sealed source **20 cm** away from a **2x2 grid** of CsI detectors in a **4-pixel MPD** arrangement.
- ❖ **Three positions** were chosen: on the top of the grid of pixels, on the side, and on the front.
- ❖ These positions were held **5 minutes** to provide **statistically significant counts**.
- ❖ The validation experiment was then recreated in Geant4.
- ❖ Corrections for air attenuation were applied using the Beer-Lambert law.

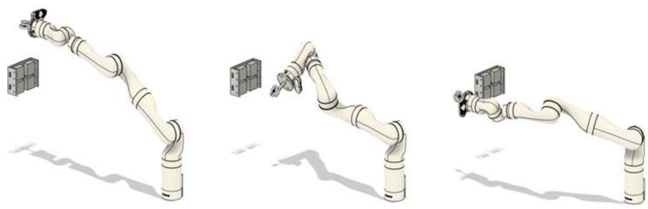


Figure 6. 3D model of the Kinova robot arm in the three positions used during the experiment with the four Hamamatsu detectors. Modelling was done in Fusion360.

Results

- ❖ Arrays that produce groups of **high-count pixels** (lower overall uniformity) tend to offer **improved localisation** performance (Figure 7), although this comes at the cost of **reduced detection efficiency**.
- ❖ Where the solid-angle effect is **more** pronounced, the detector presents **less** effective volume to the source, **increasing** Compton scattering relative to photopeak events and **reducing** intrinsic detection efficiency.
- ❖ The pixel dimensions used in this study were **too large** to provide meaningful spatial granularity. Future work will **reduce** pixel size and **increase** pixel granularity to improve resolution and optimise performance.

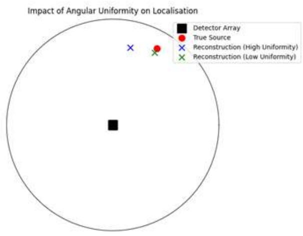


Figure 7. Conceptual illustration of the effect of angular response uniformity on source localisation, generated in Python. Lower uniformity increases localisation accuracy, whereas higher overall detector uniformity provides an improved wide-angle monitoring capacity.

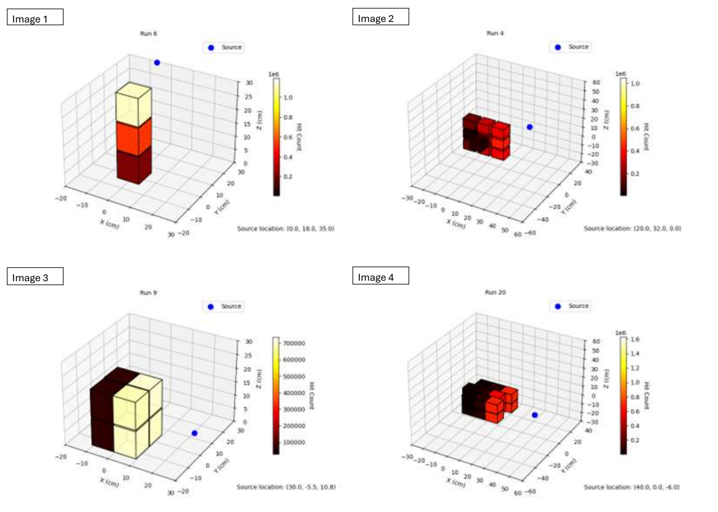


Figure 8. Heatmaps of pixel hits for four detector geometries. Image 1: Three-pixel array with source at (0, 18, 35); Image 2: Variable-depth array with source (20, 32, 0); Image 3: Eight-pixel array with source at (30, -5.5, 10.8); Image 4: Brick-bond array with source (40, 0, -6); Variations in relative pixel counts were driven by shielding effects and geometry-dependent attenuation. Heatmaps were generated in Python using CSV output from Geant4.

Conclusions

- ❖ Whilst cubic arrays demonstrated superior performance and offered the **most practical compromise** between performance and manufacturability, novel arrays showed **potential for better localisation ability**
- ❖ Non-cubic geometries introduced **asymmetry** and **complexity** without yielding appreciable improvements
- ❖ Future research should explore larger arrays and more granular, smaller arrays to identify the 'goldilocks' zone