CAMIS: A Cylindrical Active Mask Imaging System

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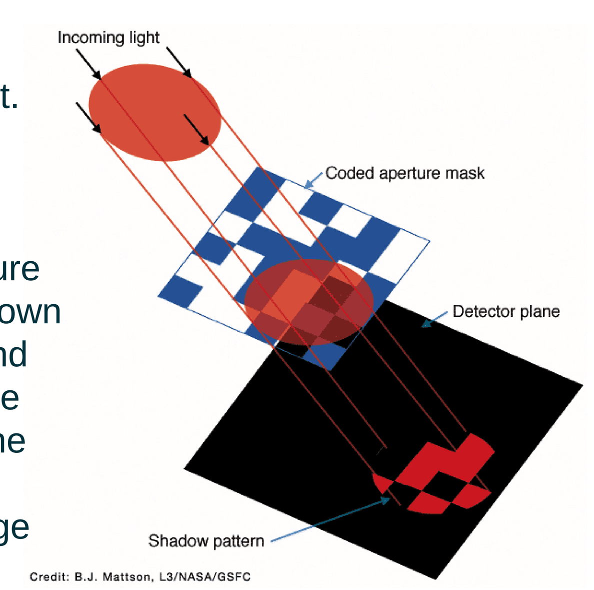
Introduction

The ability to detect and localize or map radiological materials with high sensitivity and specificity in complex and dynamic environments poses an ongoing challenge in nuclear security, emergency response and consequence management, and environmental management. In order to detect radiological materials at stand-off distances typical of urban environments, large detectors or detector arrays are required to overcome the inverse squared intensity loss with increasing distance as well as potential shielding and attenuation of radiation sources of interest [1-4]. Systems are required that can detect, identify, and localize radioactive materials quickly and in addition provide contextual visual information to adjudicate potential alarms. Approaches explored thus far employ large-area radiation imaging methodologies based on two-dimensional (2D) arrangements of detectors. These approaches were limited in two ways:

1.) The 2D and planar arrangement of detectors limit the field-of-view (FOV) of the instruments
2.) Imaging was predominantly realized with coded apertures utilizing passive masks resulting in increased weight of the instrument and limiting the efficiency.

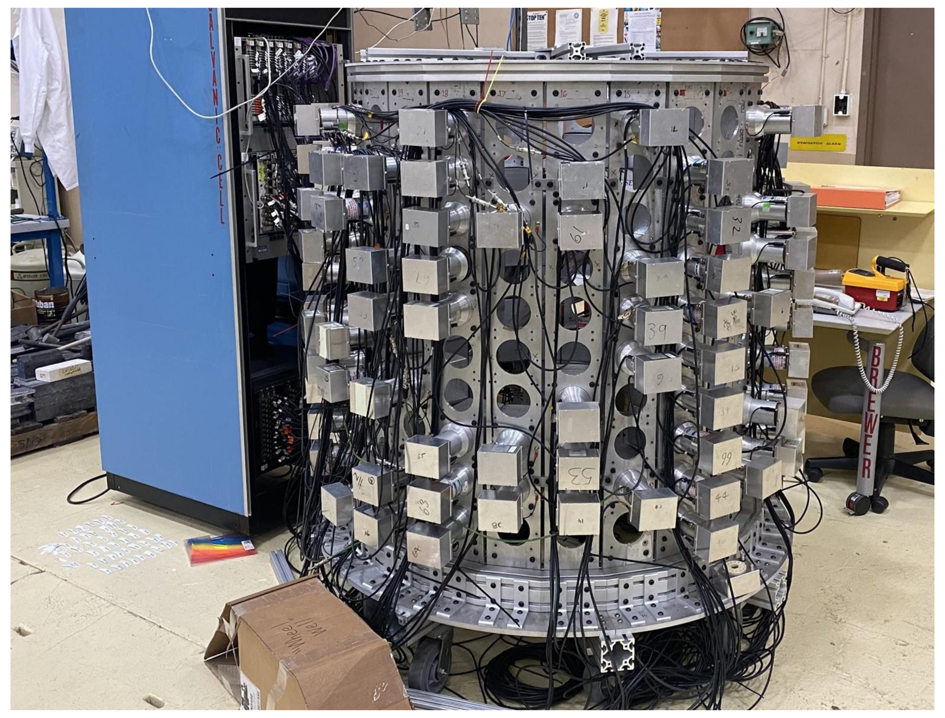
Coded Aperture Imaging

With lower energy electromagnetic radiation, light can be reflected or refracted to focus it to a single point. Higher energy photons such as gamma-rays just pass-through mirrors and lenses so another approach is required. Coded aperture systems utilize a lead mask in a known pattern to block the gamma-rays and cast a shadow on the detector plane behind the mask. Reconstructing the shadow pattern using a calculated system response produces an image of the radiation.



Imaging System Design

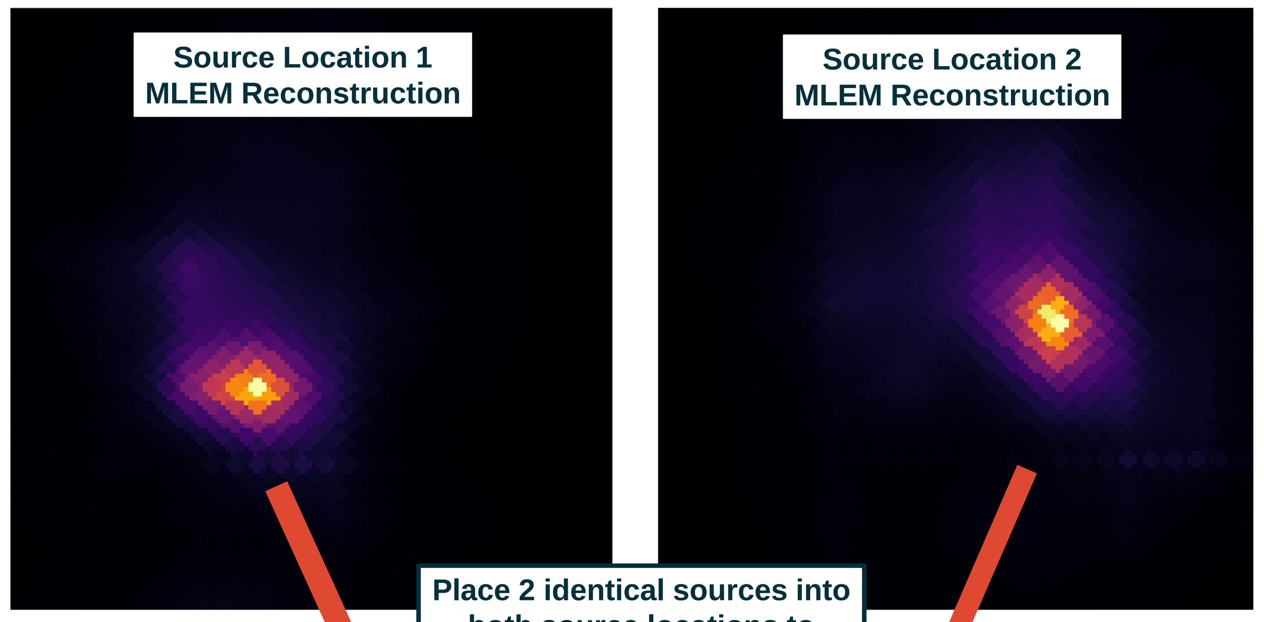
The Cylindrical Active Mask Imaging System (CAMIS) consists of 128 (10cm)³ NaI(Tl) detectors arranged over 240 possible inward-facing positions on a cylindrical surface. The outer diameter of this system is just over 1.4m with 24 individual 1.2m Al columns, each providing 10 detector slots for a total height of 1.6m. Removable caster wheels permit for mobile deployment with the option to be mounted in a standard van.

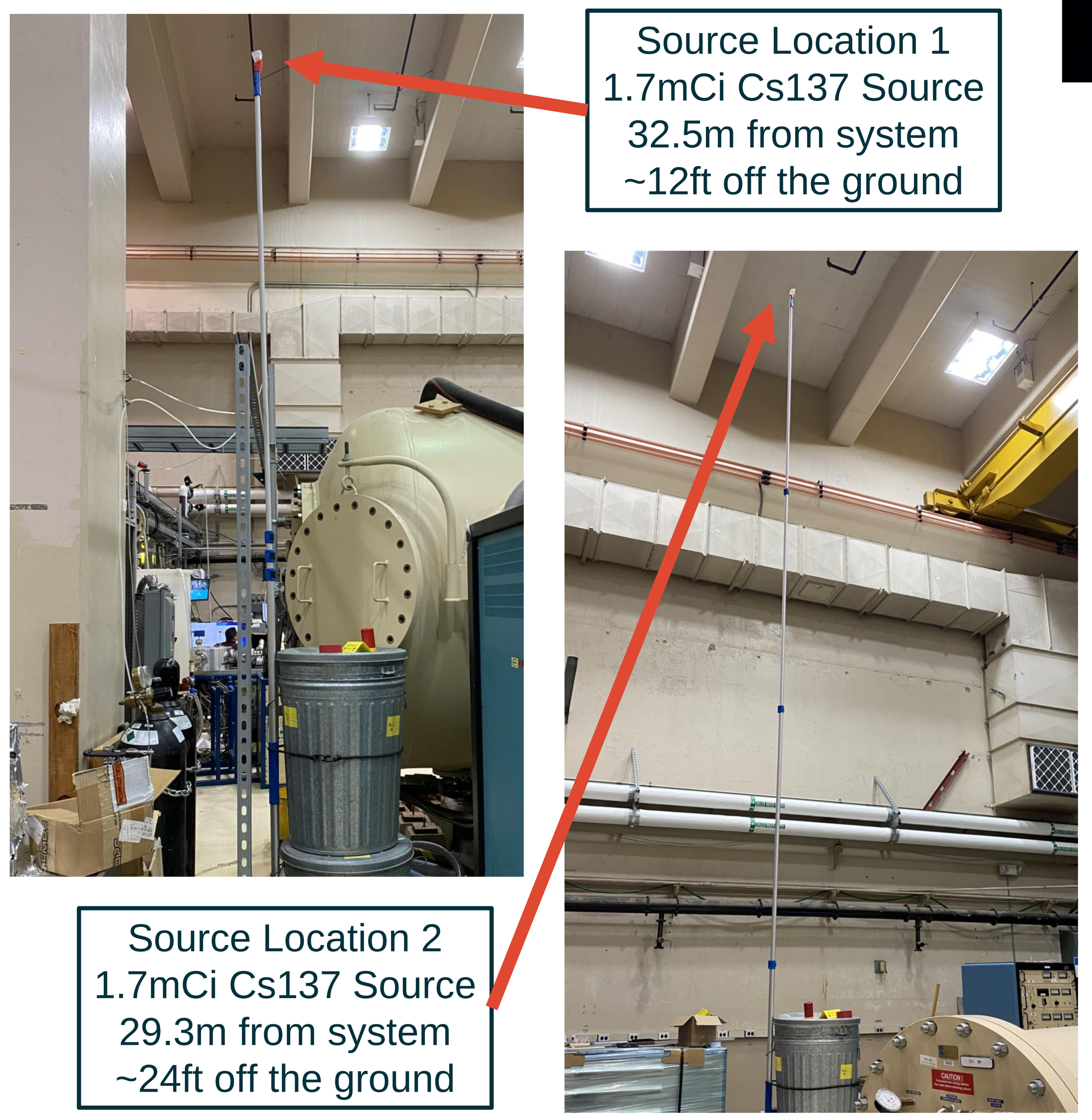


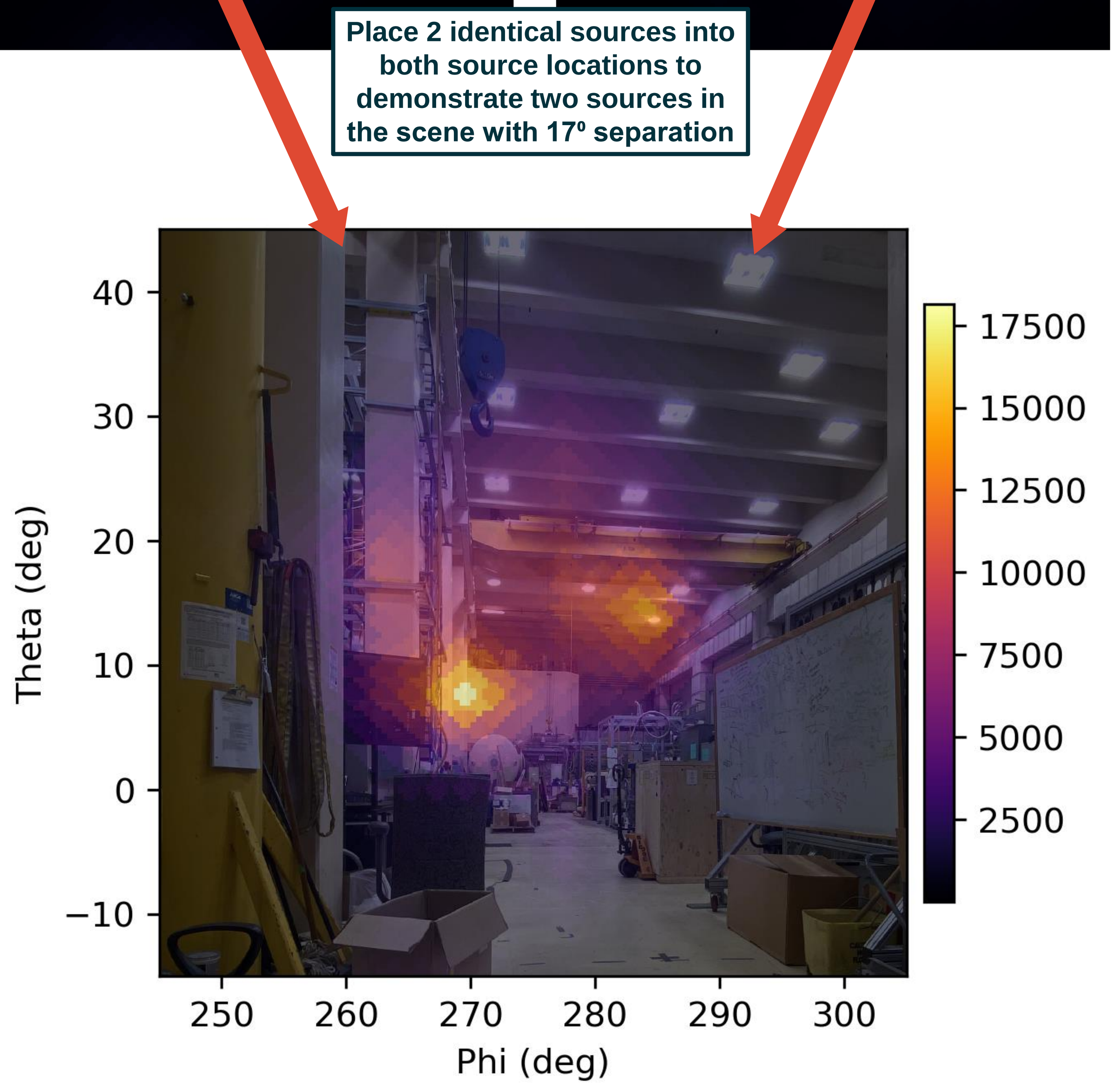
Fully assembled imaging system with data acquisition connected on the left

Measurements and Imaging Results

Inside the lab, we set up multiple measurements where we taped a 1.7mCi Cs137 source to the end of a window washing pole. The pole was placed at multiple different angular locations at ~30m away from the system. At each location, the source was raised to 24ft at 6ft increments where CAMIS was run to collect data for 10 minutes at each source location. A 15-minute background spectra was also collected using the K40 peak as energy calibration. The data from each position was reconstructed using 75 iterations of Maximum Likelihood Expectation Maximization (MLEM) and then two source positions were chosen to test the resolving capabilities of CAMIS when there are multiple strong sources in a single scene.

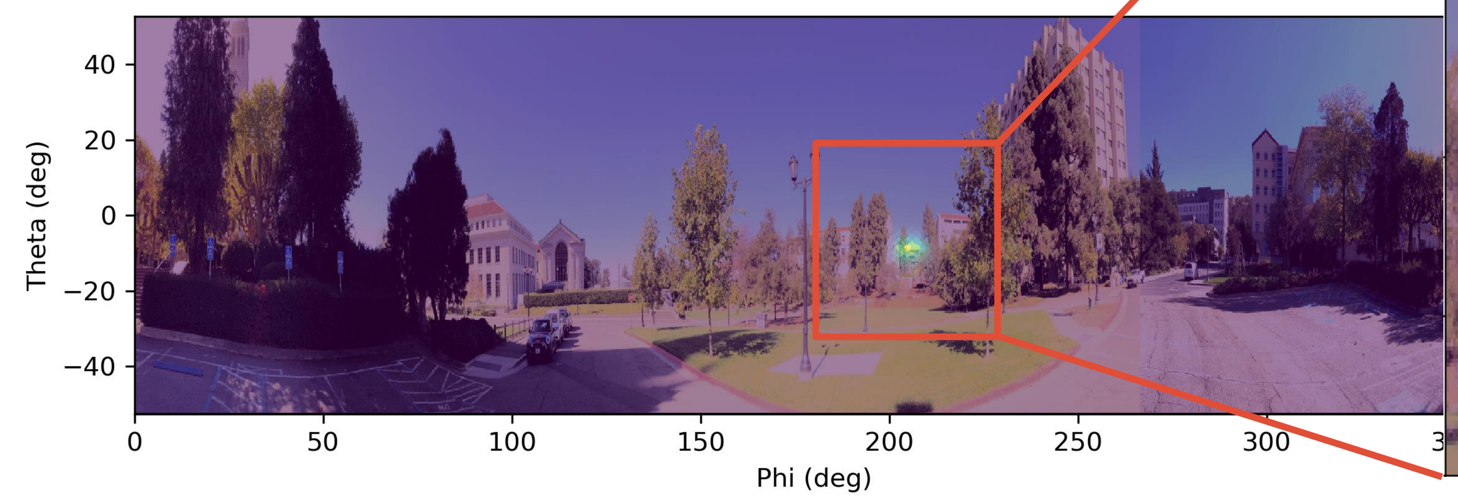


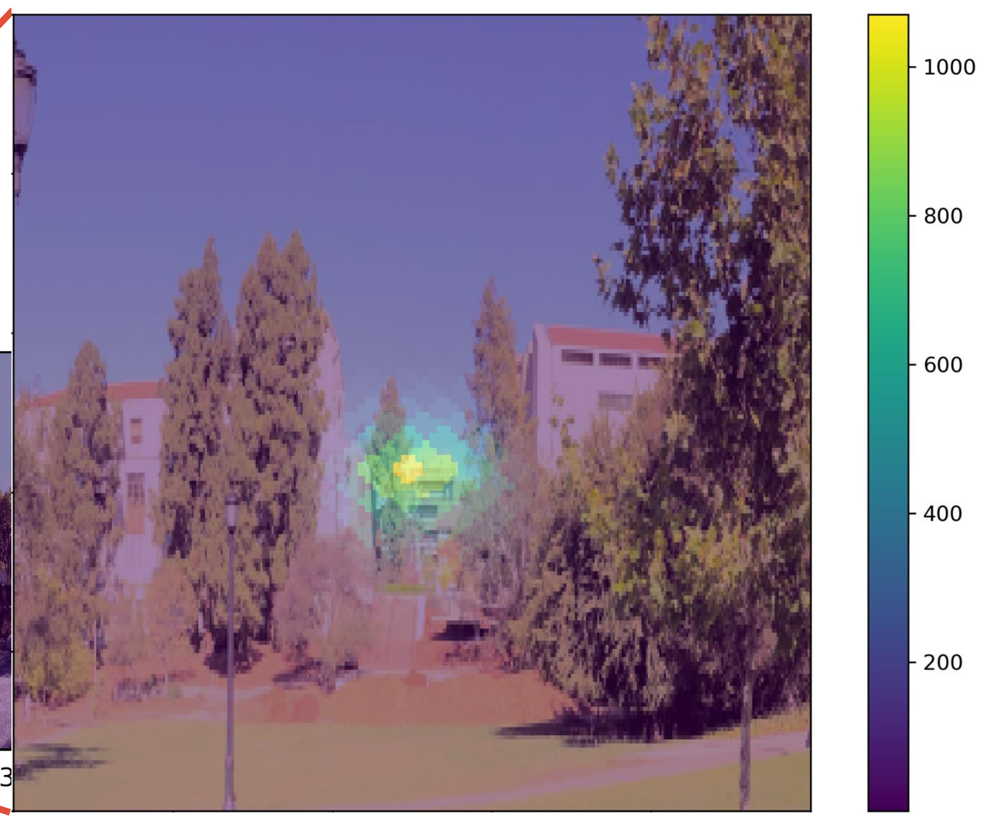




Simulated Example Deployment

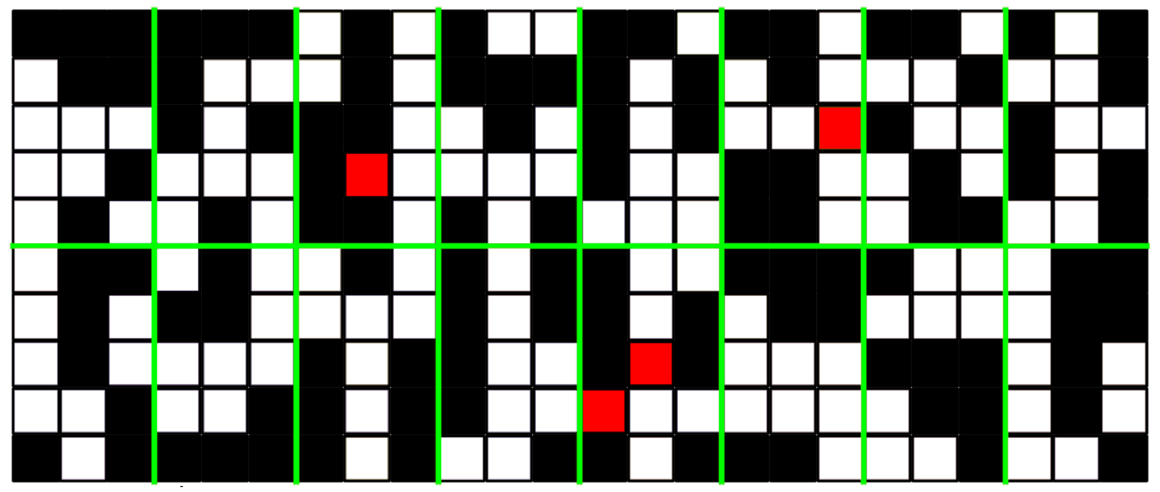
To demonstrate the effectiveness of imaging of sources far away from CAMIS, we simulated an example scenario with a source located on the roof of Etcheverry Hall, home of the Nuclear Engineering Department at UC Berkeley and CAMIS located in a small parking lot near the Campanile. In this scenario, a 5mCi Cs137 source was placed 200m away with the system acquiring data for 60 seconds, assuming a constant background rate of 40 counts per second. The source location can easily be localized to the roof of the building when overlaying a panorama image of the scene with the reconstructed radiation image.





Coded Aperture Mask Optimization

The mask for this coded aperture system was generated using a pseudo-random arrangement of detectors for a ~50% occupancy. The system response matrix was calculated using a raytracing framework in OpenGL originally developed for PRISM [5]. This geometric raytracing code models the detectors as ideal attenuators while ignoring the structure of the frame. The optimization procedure starts with a random initial configuration and iterates on the populated locations of the detector elements using the "Great Deluge algorithm" [6]. During each iteration of the algorithm, a figure of merit (FOM) metric was calculated on the mask at that step. The FOM metric was calculated by averaging the mean and variance of both the signal-to-blur ratio (SBR) and the sensitivity of every pixel, the same used for the optimization of the mask chosen for PRISM [5]. In addition, the mask pattern was refined by masking the partially encoded polar portions and splitting the optimization task among 16 sub-masks with a uniform number of detectors to ensure a more uniform detector distribution and system sensitivity across the total 2D surface. These additional restrictions on the iterative optimization of the masks pose no imaging performance deficit while simultaneously providing a mechanical advantage by balancing the weight distribution.



Final optimized mask used on CAMIS, the green lines separate the 16 individual sub-masks. The red detector locations indicate positions where the detectors were not operational for the images shown here

Conclusion

We have designed and constructed a new imaging system which provides improved gamma-ray detection and imaging capabilities for far-field and cluttered environments based on a cylindrical arrangement of 128 NaI(Tl) detectors. Using CAMIS we were able to detect and localize a Cs137 source in a cluttered environment. We also were able to demonstrate the ability to distinguish between two sources in the same scene. The arrangement of the detectors on a cylindrical frame allows coded-aperture imaging without using passive masks and at the same time providing an effective area of 1m² over 360°.

References

[1] K.-P. Ziock, et al., "Two-Sided Coded-Aperture Imaging Without a Detector Plane", in: IEEE Nuclear Science Symposium Conference Record, 2008. NSS '08, 2008, pp. 634–641
[2] E.A. Wulf, et al., "MISTI Imaging and Source Localization", in: IEEE Nuclear Science Symposium Conference Record, 2008. NSS '08, 2008, pp. 2413–2417
[3] M. Bandstra, et al.,"RadMAP: The Radiological Multi-sensor Analysis Platform", Nucl. Instr. Meth. A 840 (2016) 59
[4] J. C. Curtis, et al., "Simulation and validation of the mobile urban radiation search gamma-ray detector response," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2018.
[5] D. Hellfeld, et al., "A Spherical Active Coded Aperture for 4π Gamma-ray Imaging", IEEE Transactions in Nuclear Science 64 (2017) 2837.
[6] G. Dueck, "New optimization heuristics - the Great Deluge algorithm and the Record-to-Record Travel," J. of Comp. Phys., vol. 104, no. 1, pp. 86–92, 1993.

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