Detecting small low emission radiating sources

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Problem

Goal *Prevent influx of weapon grade nuclear material through border checkpoints.*

Idea

- Use passive detector gates to classify freight as suspicious/non-suspicious
- Search suspicious freight manually

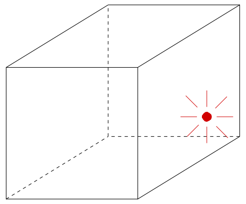
Issues

- Severe time constraints for detection
- Low emission from source, typically within a much stronger background
- Manual searches expensive and time-consuming (need to avoid false positives)

Setting

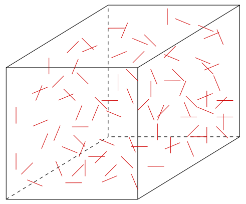
- Detect γ-photons, neutrons exiting cargo
- Sources are expected to be weak and shielded
- Background radiation my be orders of magnitude stronger than source (SNR $\sim$0.1%)

Direction insensitive measurements are not sufficient for detection as they cannot distinguish between source and background particles.



Assumptions

- Source is geometrically small compared to detection region
- Background radiation is random
- Source and background particles are indistinguishable
- Some directional information about detected particles is available

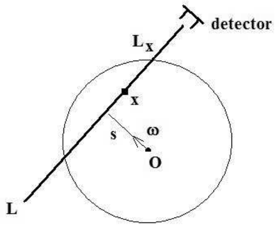


SPECT (Single photon emission computed tomography) imaging

- Let f be unknown source distribution, μ attenuation
- Measurements are integrals over lines L:

$$T_\mu f(L) = \int_L f(x) e^{-\int_L \mu(y)\,dy}\,dx$$

- T is attenuated Radon transform
- Lines are parametrized by normal ω and signed distance s to origin



Problem

- Collimation is required, which would eliminate the weak signal
- Radon transform model does not apply when source is weak
- Reconstruction schemes cannot handle strong noise in signal

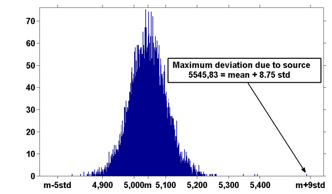
Backprojection

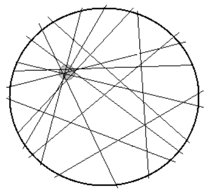
Small sources are geometrically singular, can this be used in detection?

- Assume we know the number of particles $g(\omega, s)$ that were detected coming from a line with direction ω and distance s from origin. Backprojection operator is given by

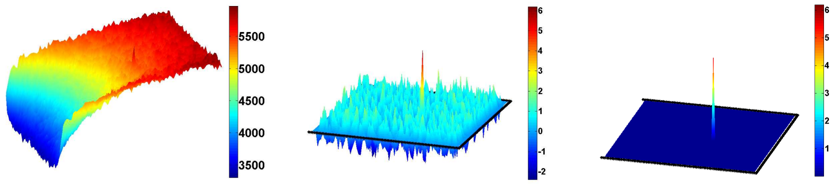
$$T^\# g(x) = \int_{|\omega|=1} g(\omega, x\cdot\omega)\,d\omega$$

- At point x, $T^\#$ integrates over all lines passing through x
- Reveals areas of unusually high concentration of lines
- Allows estimation of confidence of detection





2D results (using a detector array gate)

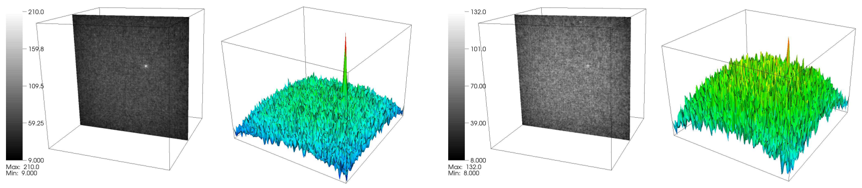


- Detectors along three sides of a square
- 2D backprojection from x-ray measurements
- 10^6 background particles, $\sim$1000 source particles (SNR $\sim$0.1%)
- After subtraction of local means
- Unit is one standard deviation from local mean
- After thresholding at 3.5 std devs
- Accurate detection of single source
- Detection confidence $\sim$99.99%

3D results

- 3D backprojection from x-ray measurements along eight sides of a cube
- 10^6 background particles, 500 (left) and 200 (right) source particles
- Images show backprojection values along cutplane through center of cube

SNR $\sim$0.05% SNR $\sim$0.02%

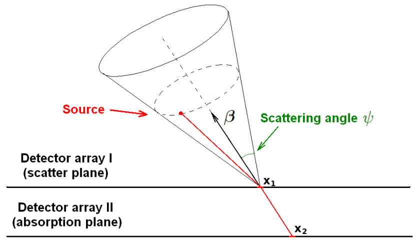


Compton camera measurements

- Measure cone of possible directions for each particle
- Does not discard any particles unlike collimated detectors
- Measurements are given by:

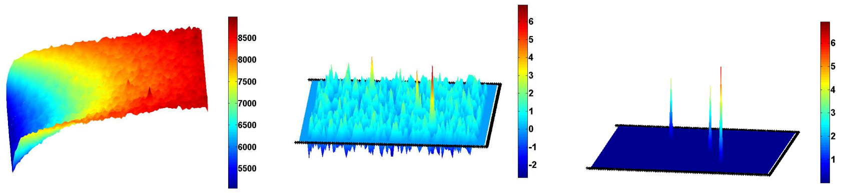
$$\mathcal{C}f(x_1, \beta, \psi) = \int_{\mathrm{cone}(x_1,\beta,\psi)} f(y)\,dS$$

where $f(y)$ is unknown source distribution ($y \in \mathbb{R}^2$ or $\mathbb{R}^3$)



- Inversion is overdetermined: data has 3 parameters in 2D, 5 in 3D
- Idea: use Compton backprojection for detection

2D results (using a detector array gate)

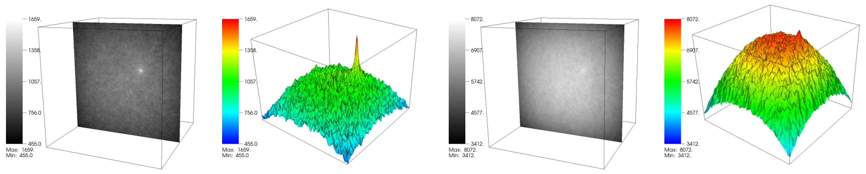


- Detectors along three sides of a square
- 2D backprojection from Compton measurements
- 10^6 background particles, $\sim$3000 source particles, SNR $\sim$0.3%
- After subtraction of local means
- Unit is one standard deviation from local mean
- After thresholding at 4.3 std devs
- Accurate detection of 3 sources
- Detection confidence > 91.97%

3D results

- 3D backprojection from Compton measurements along eight sides of a cube
- 10^6 background particles, 10^4 (left) and 7000 (right) source particles
- Images show backprojection values along cutplane through center of source

SNR $\sim$1% SNR $\sim$0.7%



References

- *Detecting small low emission radiating sources*, M. Allmaras, D. Darrow, Y. Hristova, G. Kanschat, P. Kuchment (preprint: `arXiv:1012.3373v1`)