A Volume Clearing Algorithm for Muon Tomography

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Introduction

- Millions of packages enter the US every day, but only a small percentage can be scanned without slowing down the process
- Nuclear material can be easily smuggled by using lead shielding to hide the emitting radiation
- There is a need to see through lead shielding without being intrusive or time consuming

Muon Tomography

- 3D scanning method uses naturally occurring muon showers
- Muon passing through a dense material scatters in its trajectory
- A muon tomography station (MTS) records incoming and outgoing paths of muons
- Point and angle of scattering is recorded where the projected incoming and outgoing rays come closest (POCA)
- POCA Algorithm: Analyzing high-angle scattered points shows image of the densest materials
- A prototype cubic foot detector has been built at Florida Tech using Gas Electron Multiplier detectors positioned above, below, and on two sides of probed volume

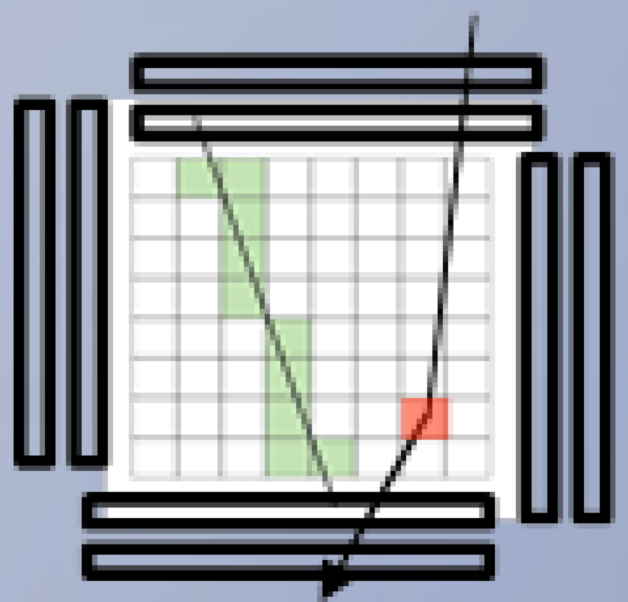
Problem & Goals

- We have no control on the slow and sparse incoming muon flux
- Visualizing sufficient scattered POCA points in target volume satisfactorily takes long time
- Muons with unscattered straight tracks are typically ignored by reconstruction algorithms

- Question 1: *Can the straight tracks be used to clear some regions of the observed volume*
- Question 2: *Can we qualify if the scan time is sufficient to clear a volume, and if not, which area(s) to focus looking into with further incoming muons*

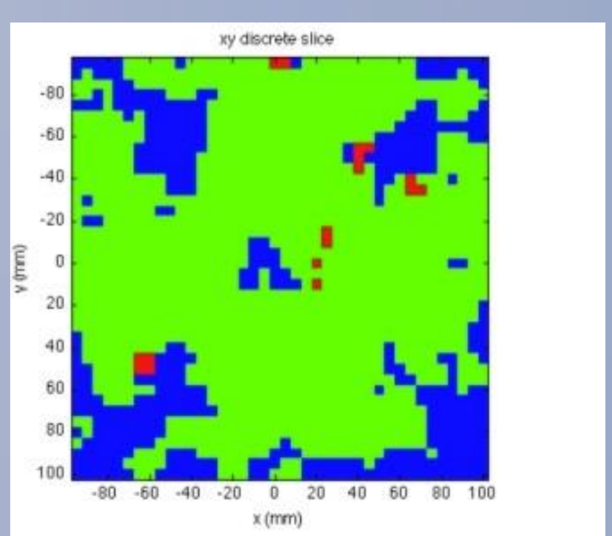
Method & Result

Scattered and Non-scattered Tracks

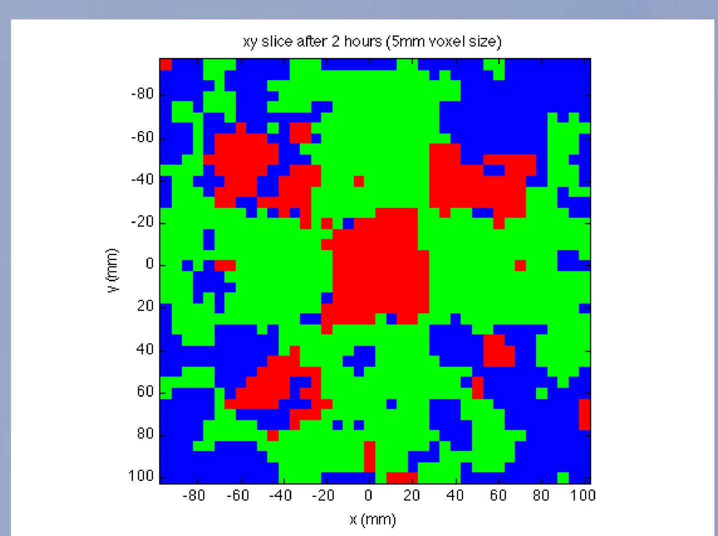


Green Voxels: No scattering material
Red Voxels: Threat
Blue Voxels: Not-sufficient data yet

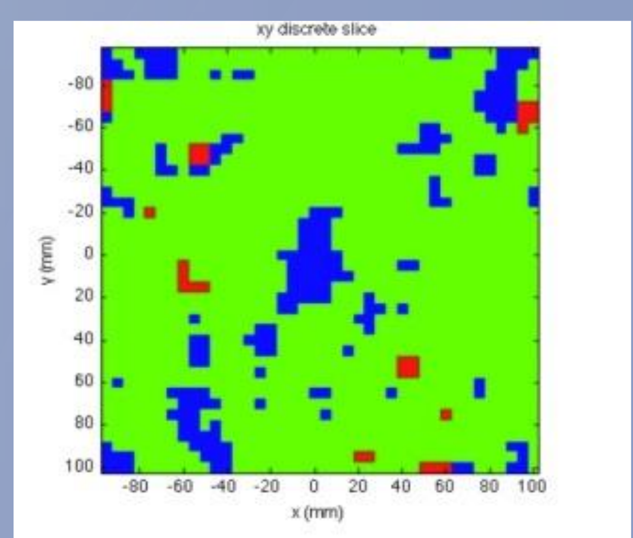
Data acquired at Muon Tomography Station With five objects placed on central plane Lead, Tungsten, DU, Tin, and Iron



Plane above the objects



At plane of the objects



Plane below the objects

3 horizontal slices of reconstructed 3D image: 2 cm above center, at center, 2cm below center

Algorithm Volume-clearing:

// Input: Set E of coincidence events: each event is (A_i, D_i, A_o, D_o) where A_i, D_i, are angle and point on a detector of the incoming muon, and A_o, D_o are those of outgoing ray of the same muon at another detector;

Probed volume V with voxels v_m: $m \le M$;

Threshold parameters: POCA angle α, POCA counts in a voxel c, tracks count in a voxel t;

// Output: Classified voxels in V for threat / cleared / insufficient-information types

// Ray tracing part of the algorithm

1. For each event in E do
2. Draw lines l_i using A_i, D_i, and l_o using A_o, D_o ;
3. Find POCA point and angle of scattering between l_i and l_o respectively as (p, Φ);
4. If $\Phi >$ threshold angle α
5. Increment POCA count C_m of voxel v_m ;
Else
6. Ray-trace R between detector points D_i to D_o ;
7. For each voxel v_m on the ray path of R
Increment straight-track count T_m of voxel v_m ;
End For loop; // over voxel-wise countings
End For loop; // on events

// Decision making part of the algorithm

8. For each voxel v_m in V
9. If $C_m > c$ then v_m is "threat-type"
10. Else If $T_m > t$ then v_m is "cleared"
11. Else v_m is "insufficient-data"
End For loop; // over voxels
12. Return the voxels' status in V

Conclusions & Future Work

- We can clear more voxels in a given period of time than we can find sufficient scattering (POCA) points within threat voxels
- Algorithm *volume-clearing* provides the evolving scenario as muons come in, and also is highly parallelizable
- Suspicious threat voxels get indicated early enough for further waiting on information near those regions
- Quality and locations of insufficient-data type voxels may determine when to terminate a scan
- We will develop automated decision making process regarding when to stop the scanning based on statistics and machine learning.

References

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③ K. Gnanvo, LV. Grosso III, M. Hohlman, JB. Locke, A.Quintero, and D.Mitra, "Imaging of high-Z material for nuclear contraband detection with a minimal prototype of a muon tomography station based on GEM detectors," Nuclear Instruments and Methods in Physics Research A, 652 (2011) 16–20.