Programming a Radiation Detection Robot

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NERS 492

Motivation

[1]

Nuclear Accidents (Fukushima)

What's our current emergency response?

Radiation workers clean-up accident sites [2]

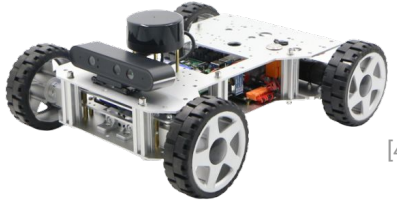
Why is this a problem?

[3]

High-levels of radiation have damaging health effects

How do we fix this?

RADical Robotics



[4]

Radiation Detection Robot

Design Objective

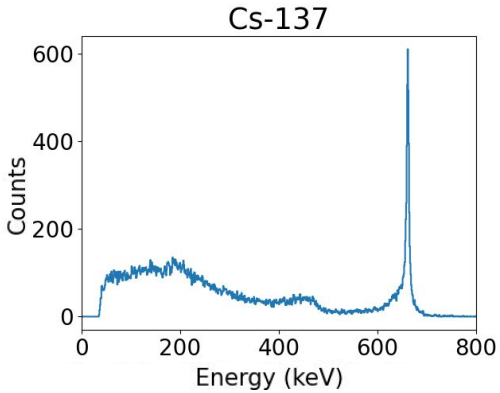
Using a provided robot and detector, we will develop algorithms to successfully identify the location of and information about radioactive sources.

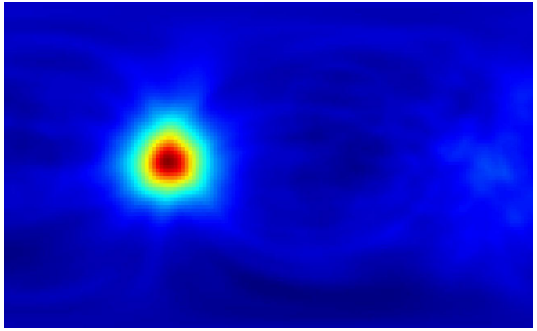
Hardware Provided

[5]

Rosbot & H3D M400 Detector

Radical Robotics' Tasks





Program Spectra & Radiation Heat Map

Approach

Localization

Robot creates a map of its surroundings

Robot localizes its current position in updated map

Radiation detection

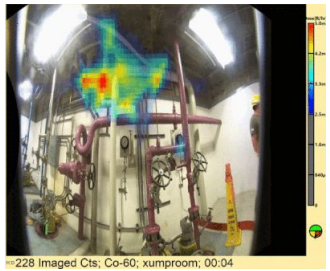
Radiation analysis scripts are run

python™

Detector takes a measurement

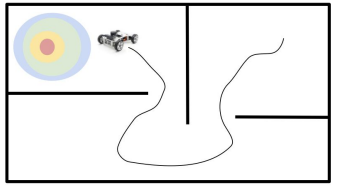
Outputs

Visual radiation map



[6]

Localization of source

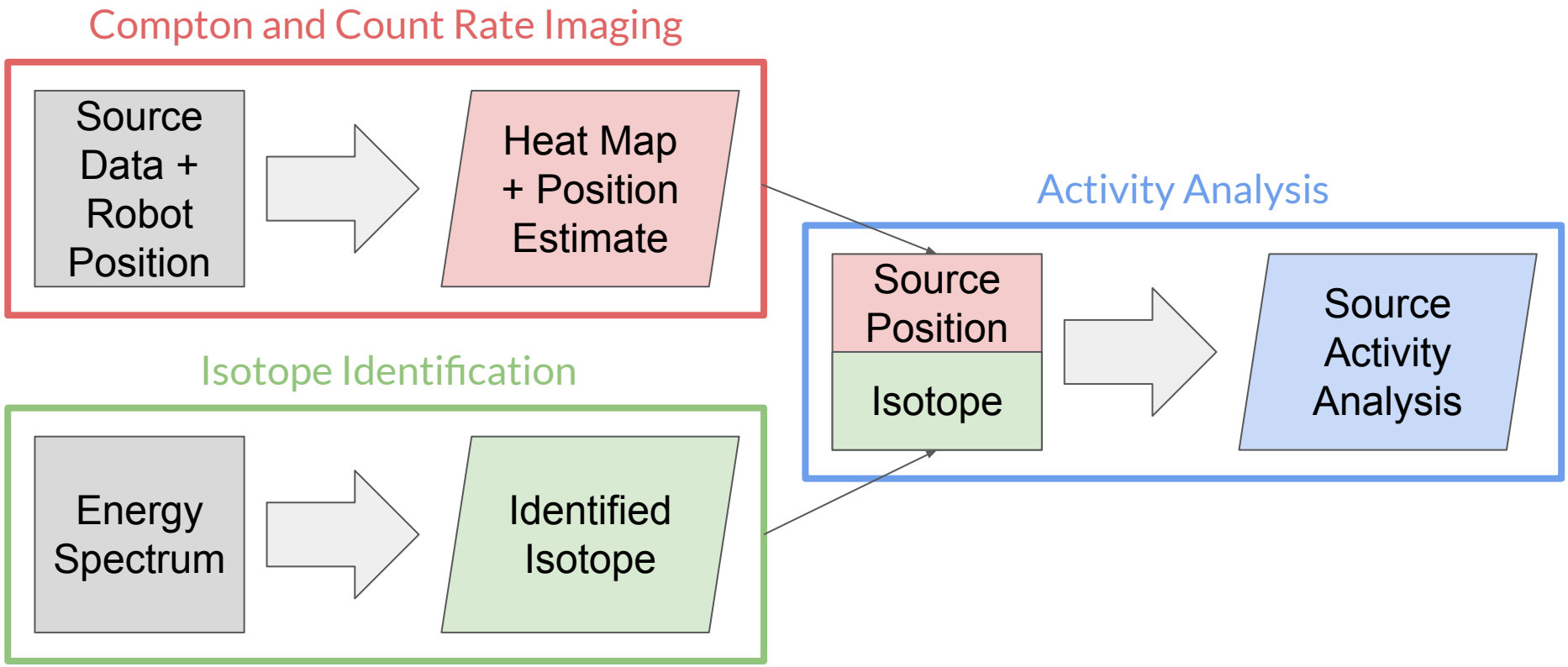


Characterization of source

[7]

Methods

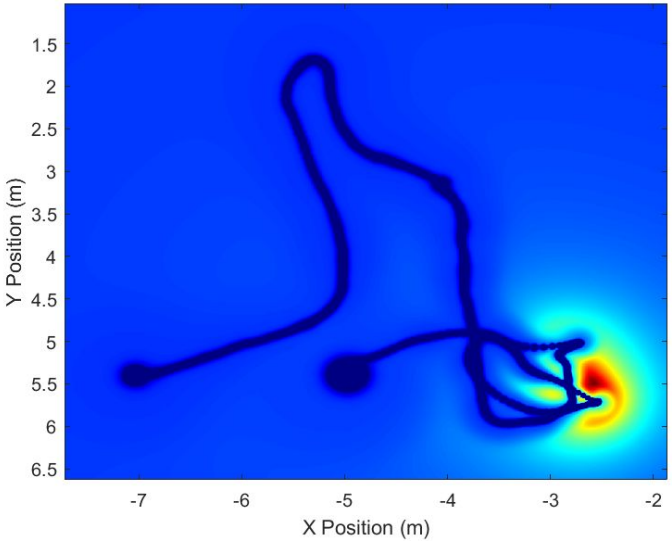
Methods Overview



Count Rate Imaging

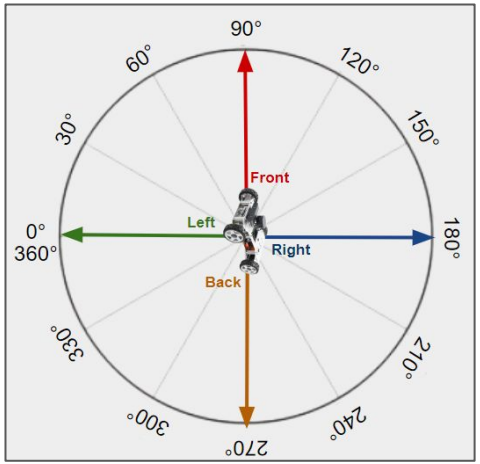
- Rosbot provides positional data, detector provides count data
- Least squares method to localize source
  - Theoretical count rates at each discrete point measured against actual recorded count rates

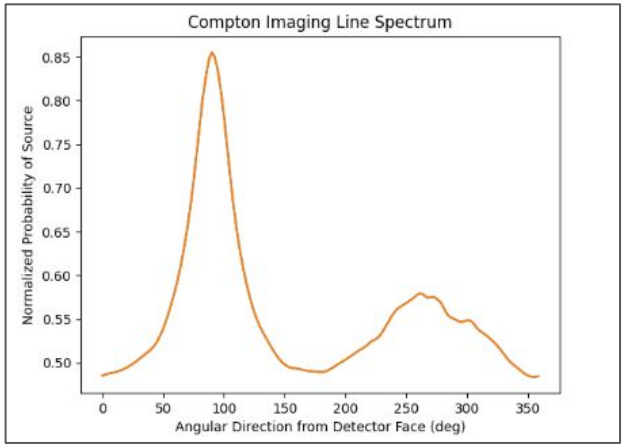
$$S_{x,y,I} = \sum_{i=1}^{n} \frac{1}{e^2} (R_{rec} - \frac{\epsilon_{int}\epsilon_{emis} I A_{det}}{4\pi r^2})^2$$

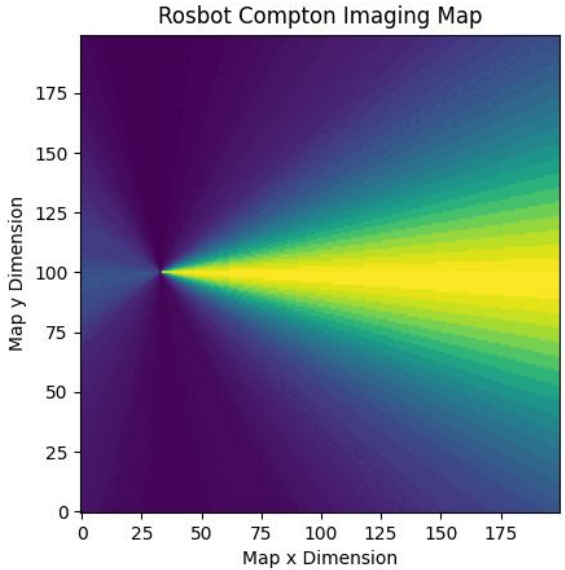


Compton Imaging

- Rosbot provides a .bif file of Compton imaging line spectrum
- Data is extracted from the line spectrum
  - Array created storing probability of source location at degree values
- Compton cone projected for each array

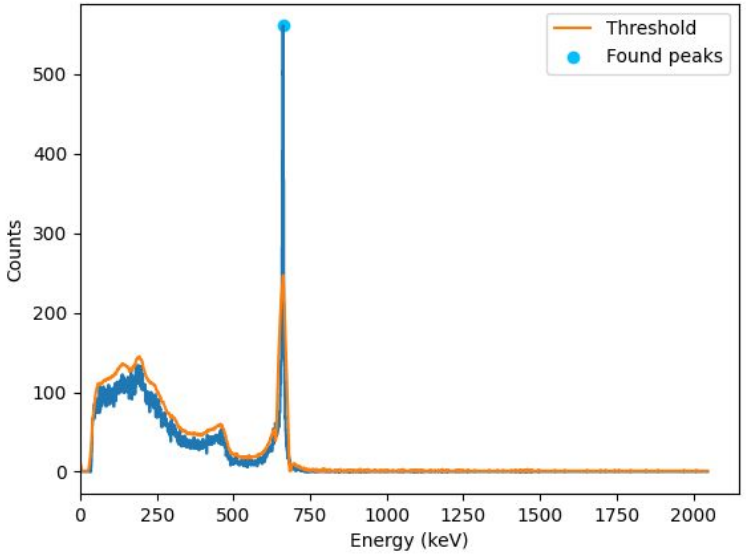


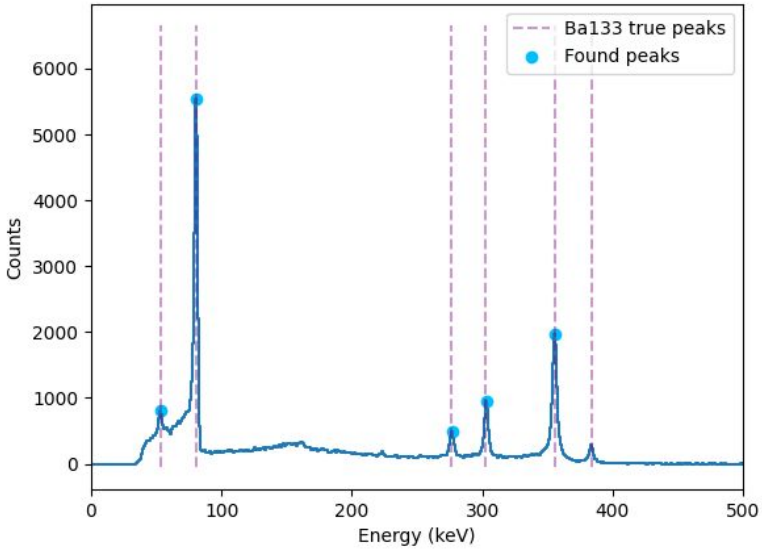




Isotope Identification

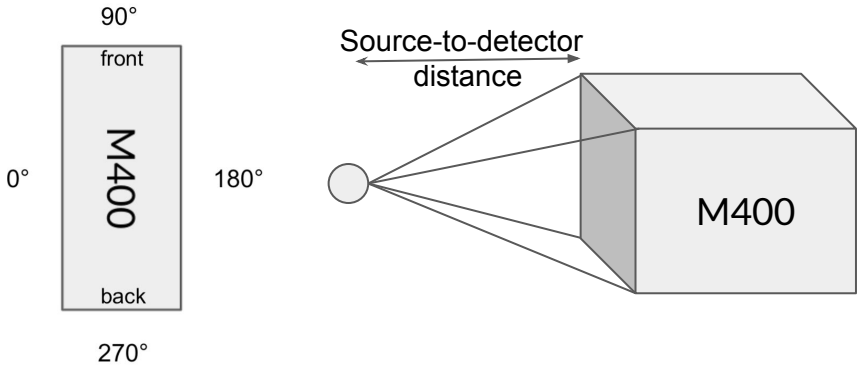
- Peak finding using SciPy
  - Height
  - Prominence
  - Width
- Comparison of found peaks to peak in isotope database
  - Atomic number
  - Element symbol
  - Mass number
  - Gamma peaks
  - Emission probability
  - X-ray peaks



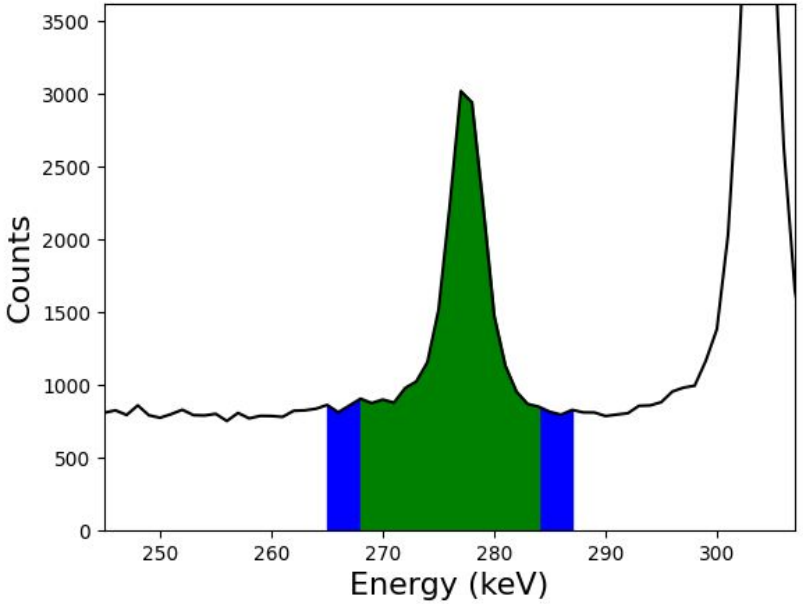


Activity Analysis

- Calibrate efficiency of detector as a function of angle
- Use distance and direction obtained from imaging

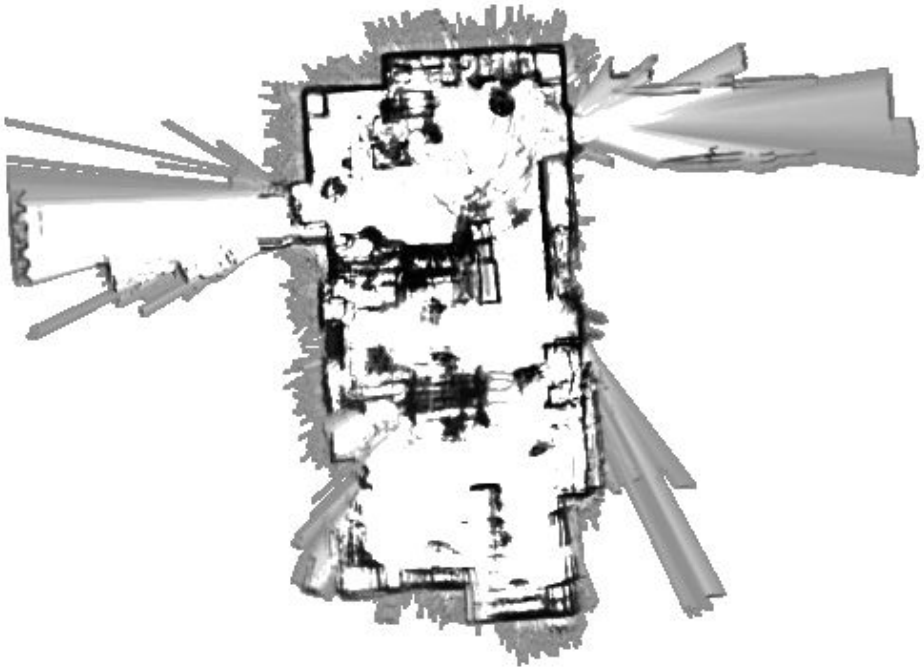


- Peak count information
  - Background continuum
  - Determine peak region of interest



Results

Light Detection and Ranging (LiDAR) maps

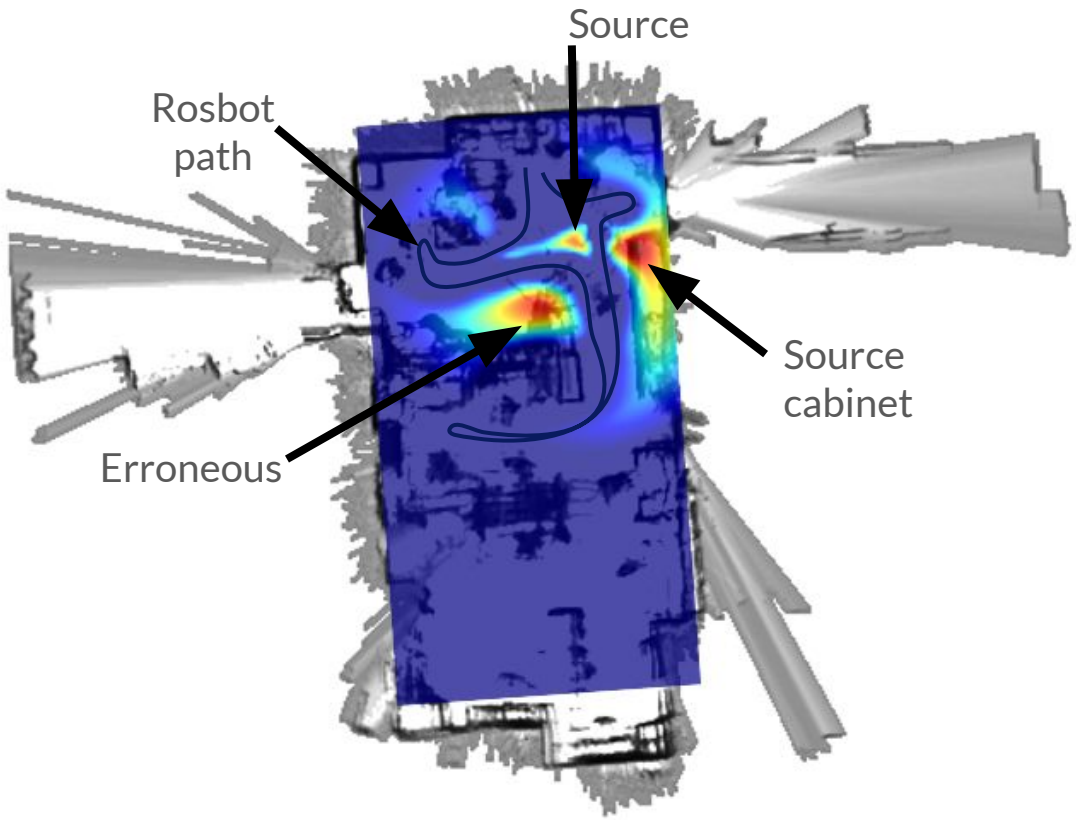


Orion Radiation Measurement Lab

Baer Room

Count Rate Imaging Results

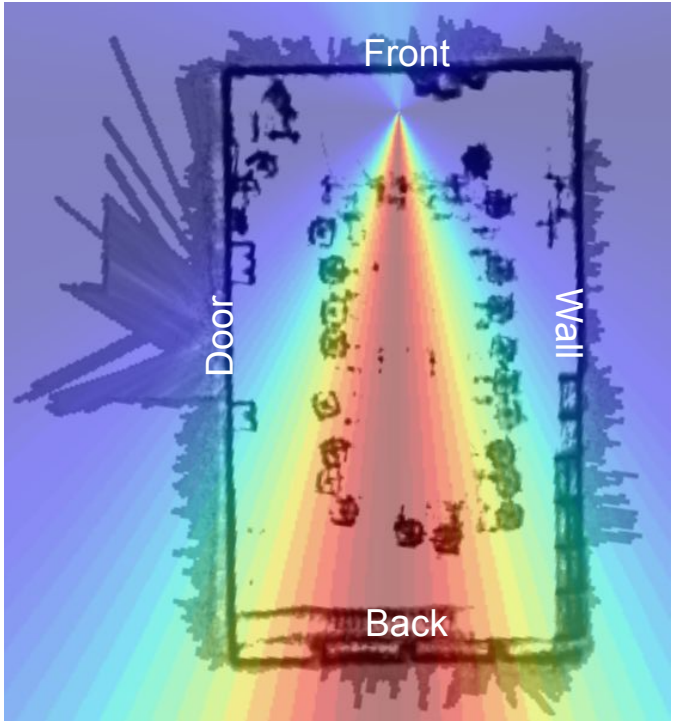
- Multiple hotspots detected
- Inaccurate localization
  - Test inaccurate by 1.8 ± 0.9 m
- Current methodology not useful if multiple sources are present
  - More testing needed



Compton Imaging Results

- Projections correctly localized Cs-137 source within:
  - 0.21 ± 0.05 m
- Compton cones correctly estimated source direction within:
  - 7.81 ± 3.05°

Source Localized on Lidar Map



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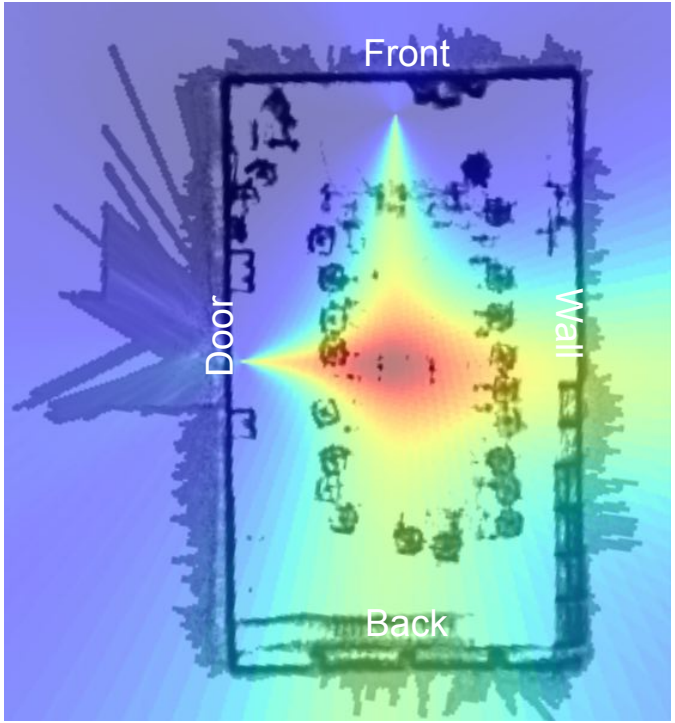

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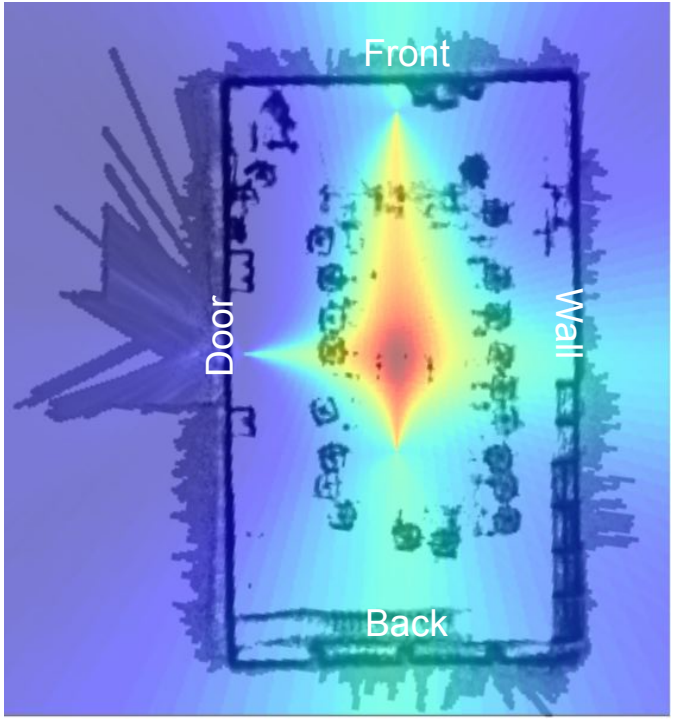

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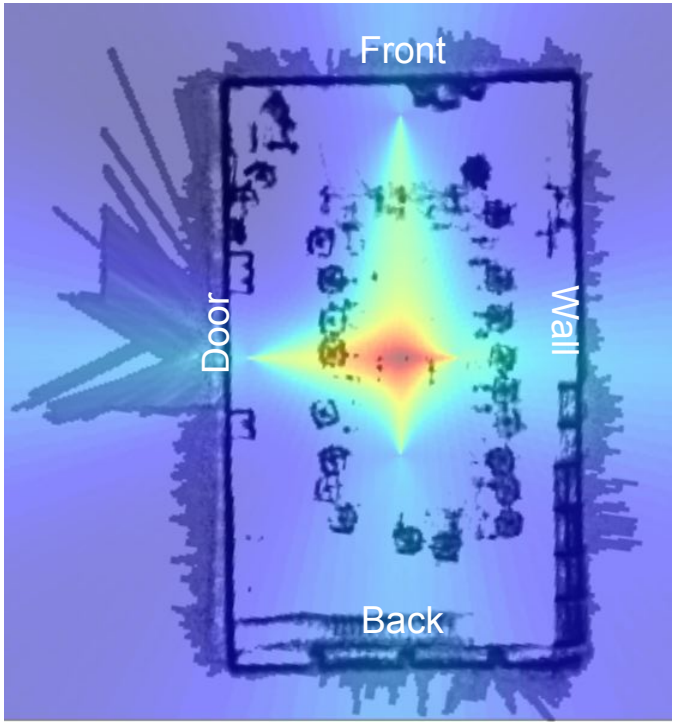

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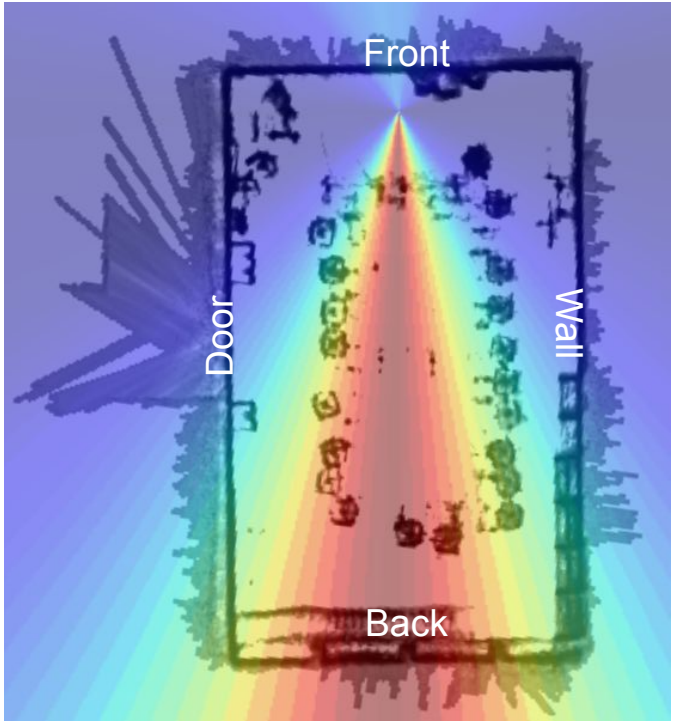
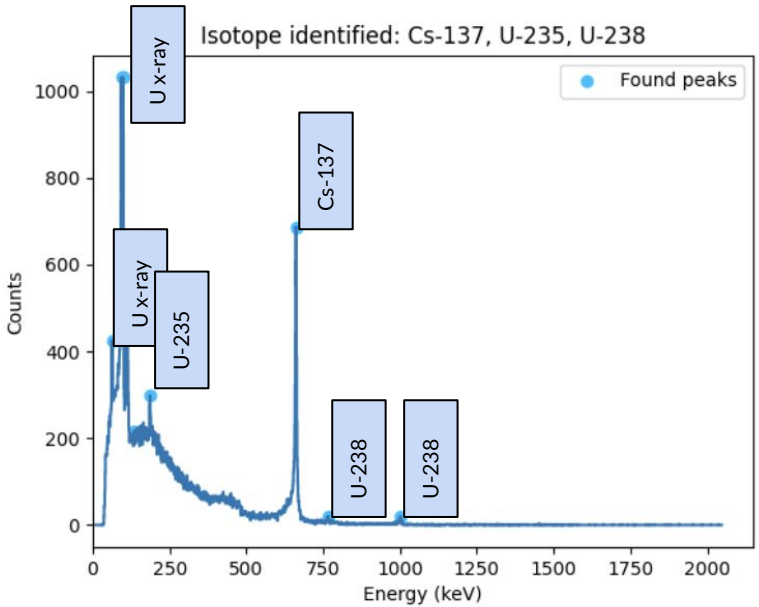
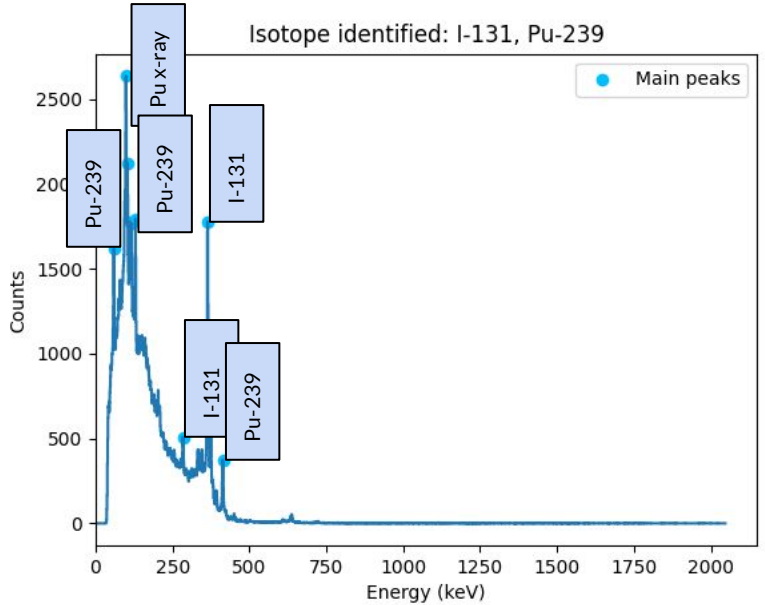


Isotope Identification Results

100% accuracy for 160 spectra

- Isotope dataset includes 160 spectra of 13 isotopes



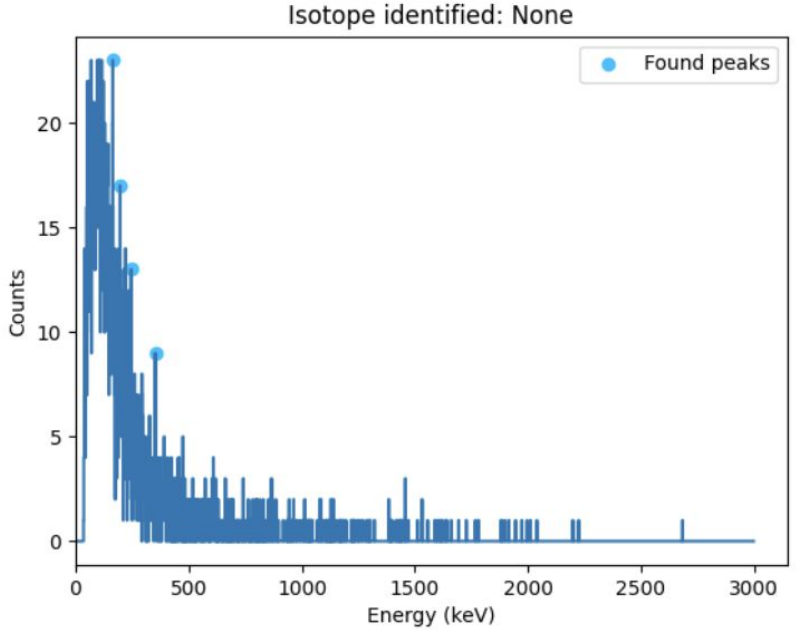


Isotopes: Am-241, Ba-133, Co-60, Cs-137, Ga-67, Ra-226, Tc-99m, Tl-201, I-131, Th-232, Depleted uranium (DU), Highly enriched uranium (HEU), Weapons grade plutonium (WGPU), Ga-67 + HEU, I-131 + WGPU, Cs-137 + DU

Isotope Identification Results

99.6% accuracy for 3002 spectra

- Background dataset includes 3002 spectra
  - Bootstrapping method

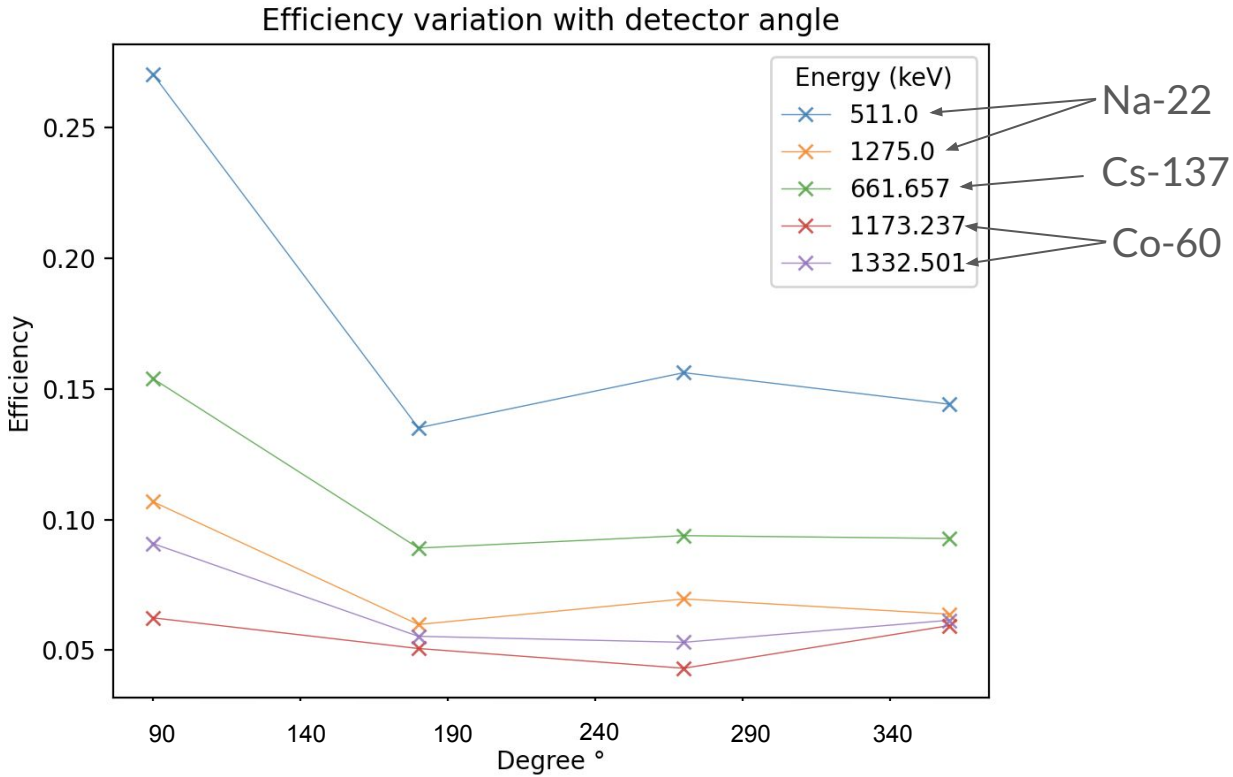


Meets IAEA National Standard Identification Criteria (N42.34) background false alarm rate requirements

Activity Analysis Results

Detector Efficiency:

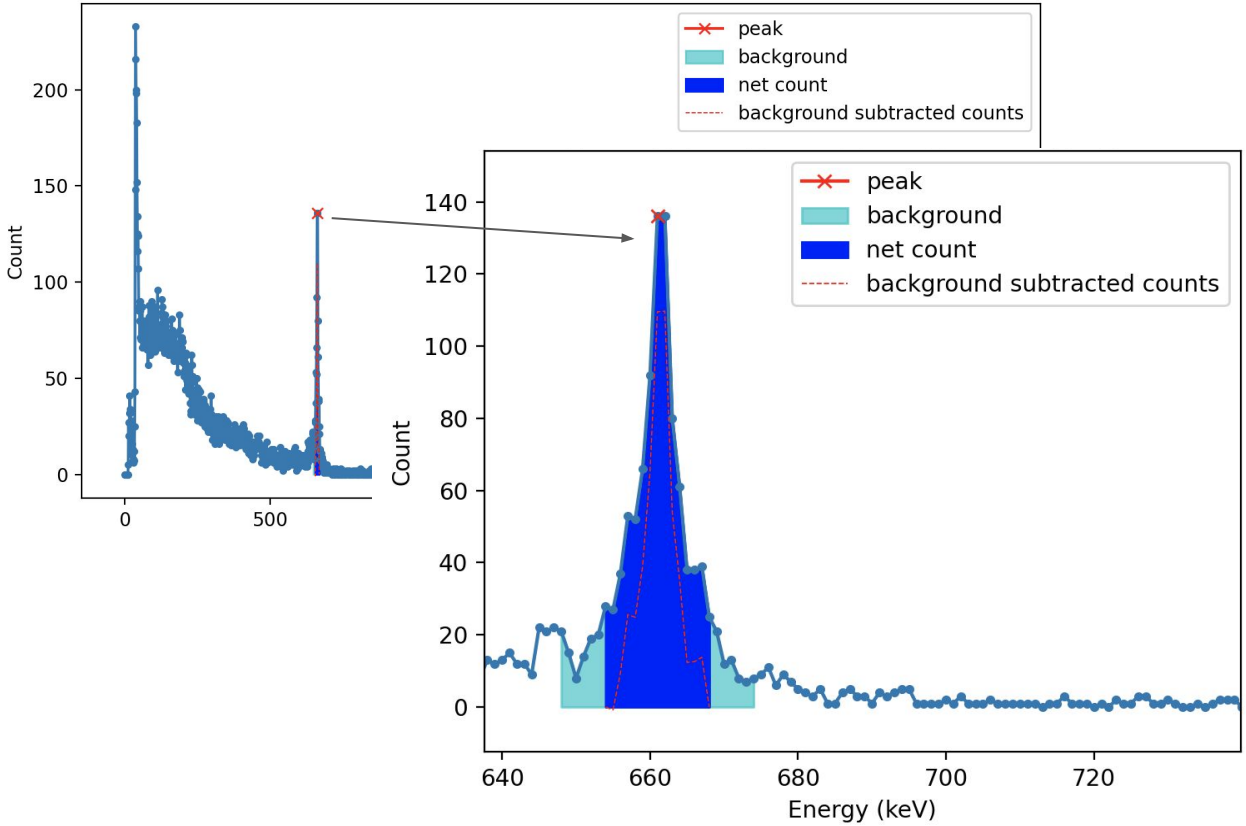
- Highest efficiency at 90° (in front of detector)
- Photon energy dependence on gamma ray interaction cross sections



Activity Analysis Results

Activity Analysis:

- Use photopeak information and isotope guess
- Test Cs-137 measurement of ~76 µCi source
  - Known location and direction
  - Estimated activity 96.2% of real activity



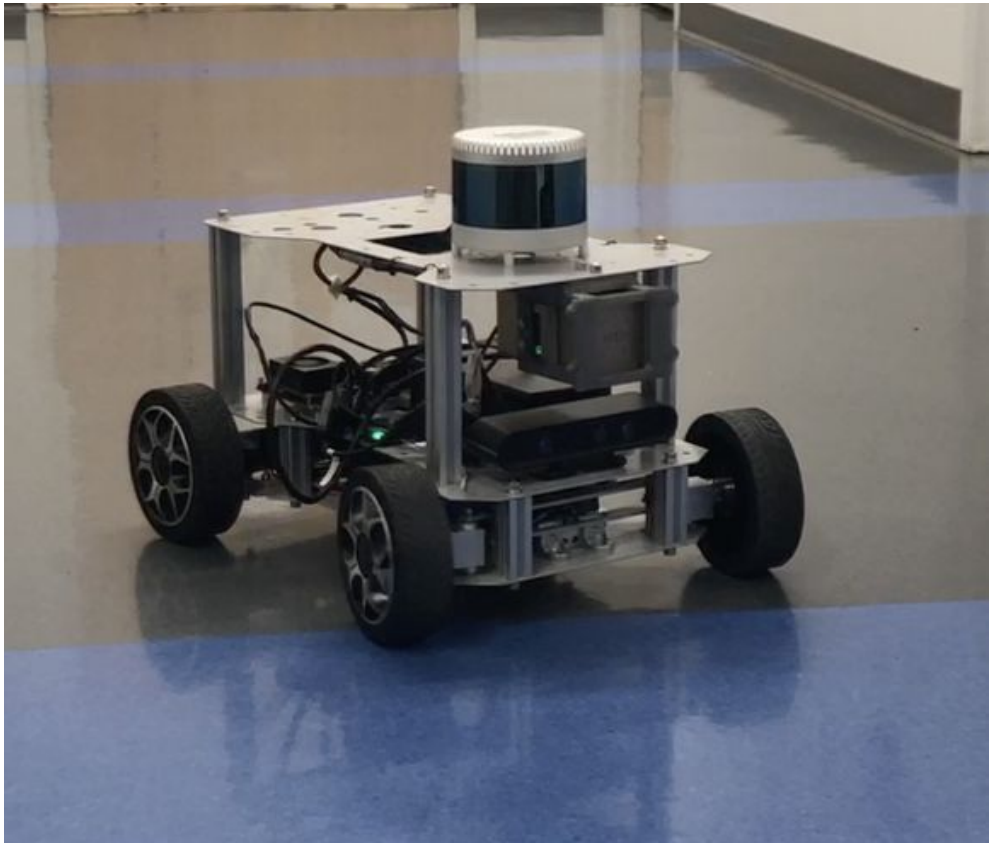
Conclusions and Future Work

Conclusions

- Radiation detection robots can be utilized to localize a source within 0.21 ± 0.05 meters of a true source location
  - Benefits include lowering occupational dose, scanning hard to reach areas, and rapid deployment of radiation survey devices
- Radiation detection robots can be used to visualize radiation hot spots
  - Compton imaging uses projected Compton cones to determine relative hotspot locations
  - Count rate imaging may be inaccurate for identifying an exact source position, but can identify general radioactive locations
- Radiation detection robots can employ methods to characterize sources
  - Isotope identification can determine the isotopes present using gamma spectroscopy
  - Activity analysis is used to roughly estimate the source activity based on efficiencies

Future Work

- Autonomous mapping
  - Develop a further iteration of processing scripts to instantly process measurement data
- Multi-isotope localization
  - Additional real world testing of environments with multiple sources
- Timing capabilities of system
  - Determine the minimal time the detector and Rosbot need to collect data in order to accurately localize and identify a source



References

[1] “FUKUSHIMA DAIICHI DISASTER,” Olivia's Blog, 31-Oct-2014.

[2] M. Yamaguchi, “An ex-fukushima worker is the first confirmed to have cancer from radiation,” Business Insider, 20-Oct-2015. [Online]. Available: https://www.businessinsider.com/an-ex-fukushima-worker-is-the-first-confirmed-to-have-cancer-from-radiation-2015-10.

[3] “U.S. EPA Radiation Education Activities: Radiation Exposure.” United States Environmental Protection Agency.

[4] “Rosbot Mini,” Oz Robotics. [Online]. Available: https://ozrobotics.com/shop/rosbot-robot-car-for-ros-beginners-and-experienced-developers.

[5] “M400 Custom Integrable Detector Module.” H3D, Ann Arbor, 2017.

[6] “How Does Gamma-Ray Imaging Work?” H3D, Ann Arbor.

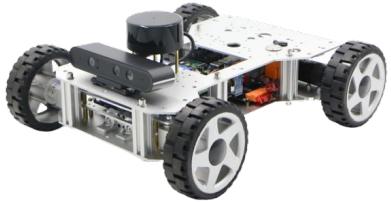
[7] “Cesium-137,” nuclear-news, Dec. 03, 2011. https://nuclear-news.net/2011/12/03/high-radioactive-cesium-levels-in-abukumagawa-river-japan/cesium-137/

Credit Statement

- **Undarmaa Ganbaatar:** Software, Data Processing, Methodology, Visualization, Formal Analysis
- **Emeline Hanna:** Methodology, Software, Data Processing, Validation, Formal Analysis, Writing
- **Katie Olivas:** Software, Data Processing, Image Development, Experimental Procedures, Organization
- **Isaac Reichow:** Software, Data Processing, Image Development, Experimental Procedures
- **David Goodman:** Conceptualization, Methodology, Software, Resources, Supervision, Project Administration, Funding Acquisition, Data Curation
- **Zhong He:** Conceptualization
- **Brian Kitchen:** Conceptualization, Methodology, Software, Resources, Supervision, Project Administration, Funding Acquisition, Data Curation

RADical Robotics

Thank you! Questions?



Extra Slides

Compton Imaging Results

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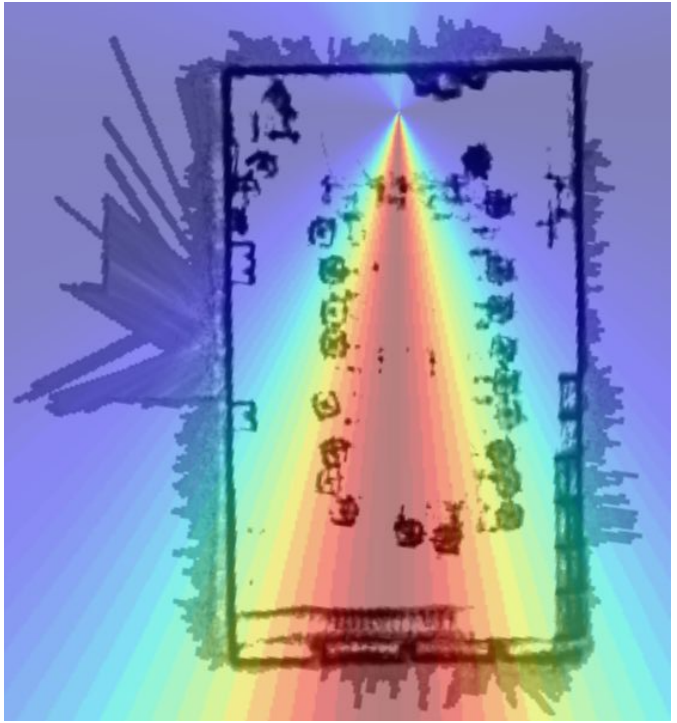
Source Localized on Lidar Map



H3D M400 Spec Sheet

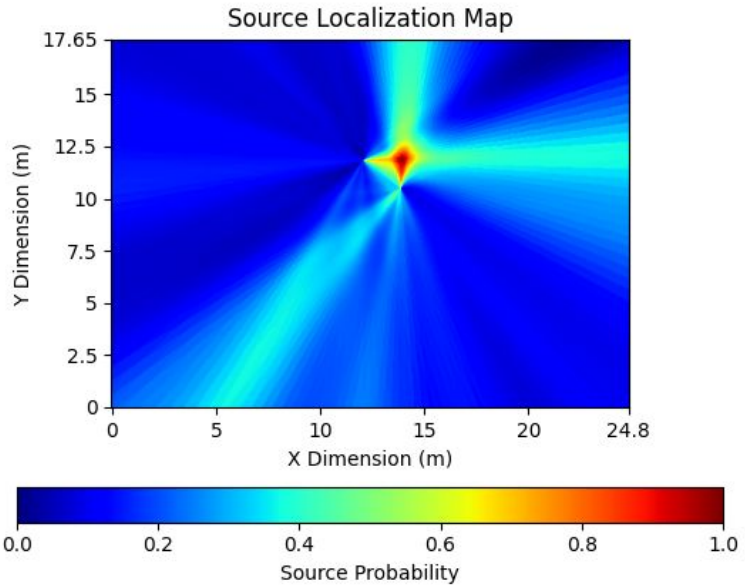
- Energy Resolution at 25℃:
  - ≤ 1.1 % FWHM at 662 keV (coincident interactions combined)
  - ≤ 0.9 % FWHM at 662 keV (coincident interactions separated)
- Sensitivity:
  - Detects 10 µCi Cs-137 at 1m (≅ 3 µR/hr) in < 22 s (in natural background)
- Spectroscopy Range
  - 50 keV to 3 MeV
- Spatial Resolution
  - <0.5 mm (≥ 140 keV)
- Count-Rate Limit:
  - 1 rem/hr (10 mSv/hr) bare Cs-137 equivalent
- Maximum Event Rate:
  - 75 kcps at <0.5-mm spatial resolution 1
  - 50 kcps at <2-mm spatial resolution

H3D M400 Spec Sheet

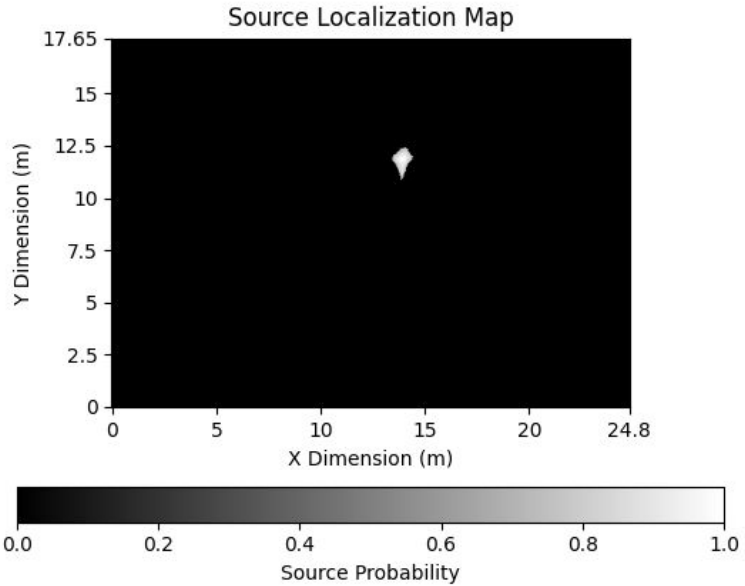
- Compton Imaging Option (M400i)
- Image Energy Range:
  - 250 keV to 3 MeV
- Field of View:
  - 4π (360°) omnidirectional
- Angular Precision:
  - ±1° source localization for all 4π (real time)
- Angular Resolution:
  - ~30° FWHM for all 4π (real time; >250 keV)
  - ~20° FWHM for all 4π (post processing; >250 keV)
- Sensitivity:
  - Localize point source of 137Cs producing ~3 μR/hr in <90 s
- Data API Options:
  - Each interaction 3D position (x, y, z)

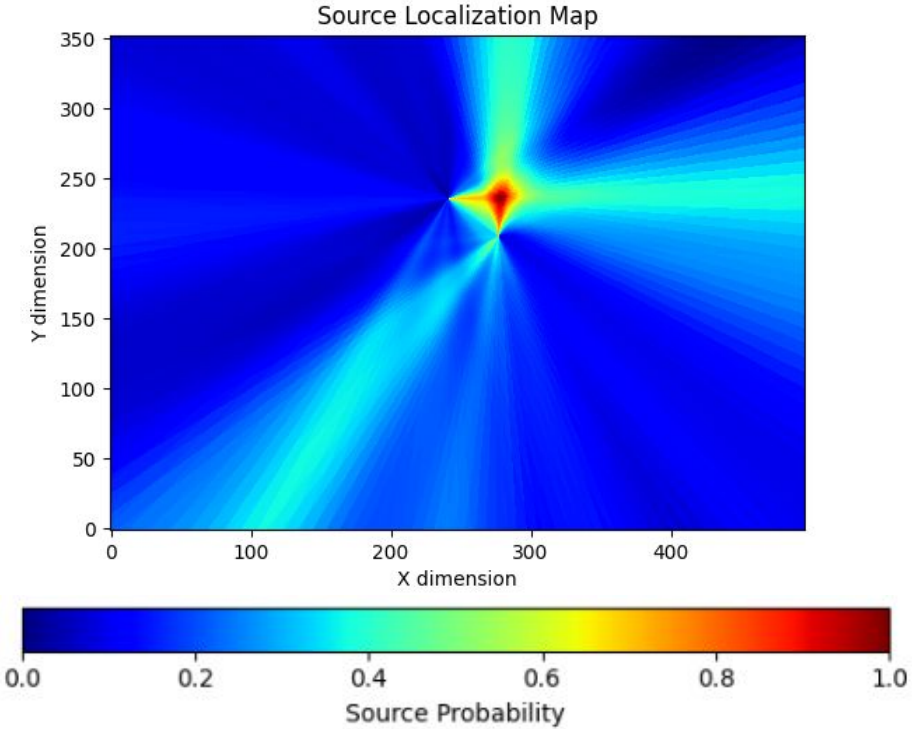
Compton Imaging Results

Compton Cone Projection Map



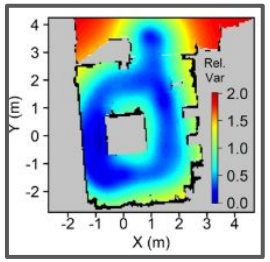
Weighted Average Projection Map




Source Localization Map
Y dimension
X dimension
0
50
100
150
200
250
300
350
0
100
200
300
400
0.0
0.2
0.4
0.6
0.8
1.0
Source Probability

Literature Review

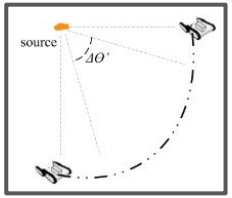
- Lancaster University Neutron Laboratory
  - Use of Gaussian process regression for radiation mapping of a nuclear reactor with a mobile robot
  - SLAM generated radiation map with $CeBr_3$ detector



[5]

- Limitations
  - Known ^{252}Cf source used (no isotope identification)
  - $CeBr_3$ was only responsive to gammas, not neutrons

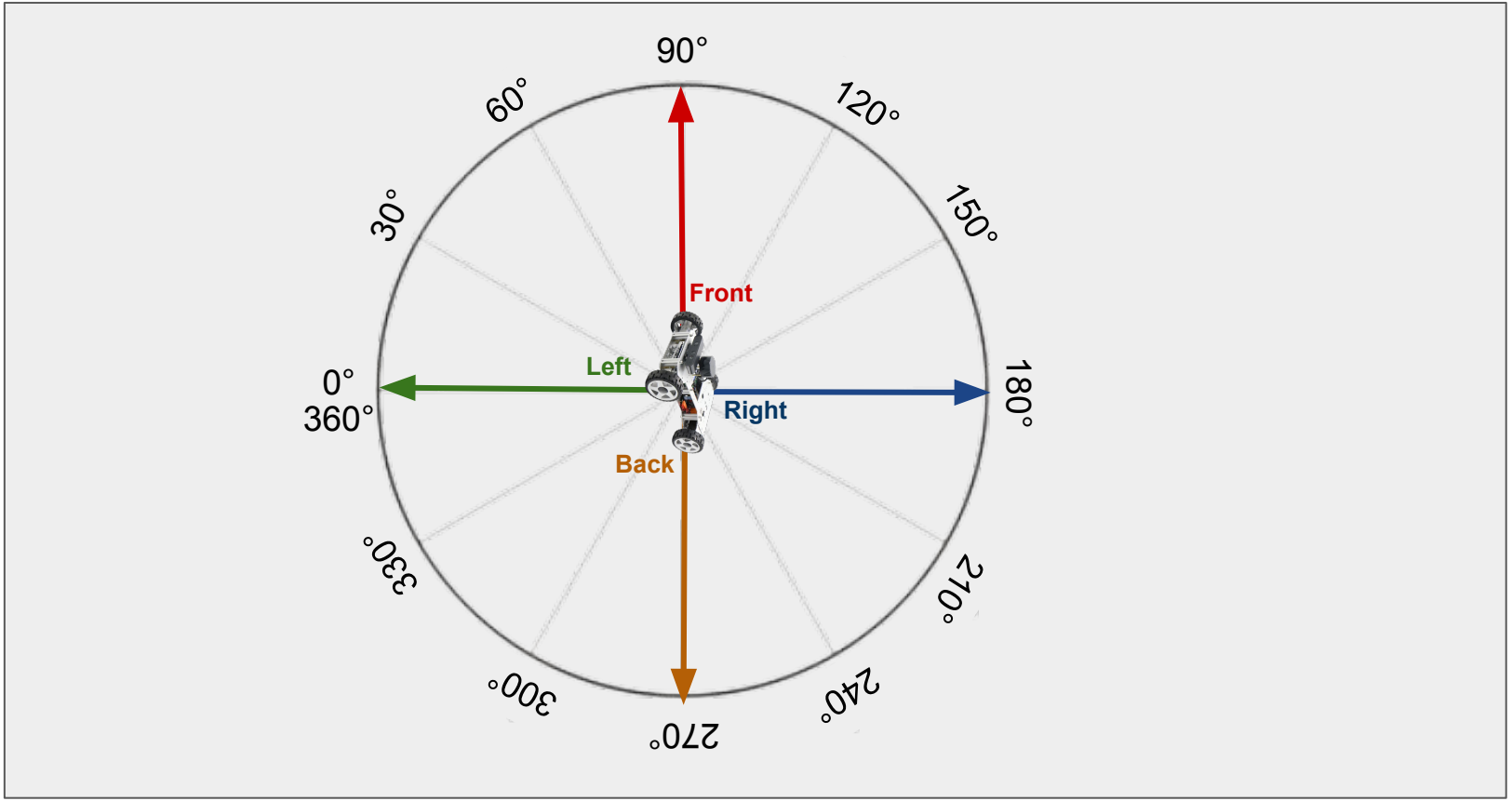
- State Key Lab of Fluid Power & Mechatronic Systems, Zhejiang University, China
  - Radioactive source recognition with moving Compton camera imaging robot using Geant4
  - Testing compton reconstruction image quality based on robot angles and distances



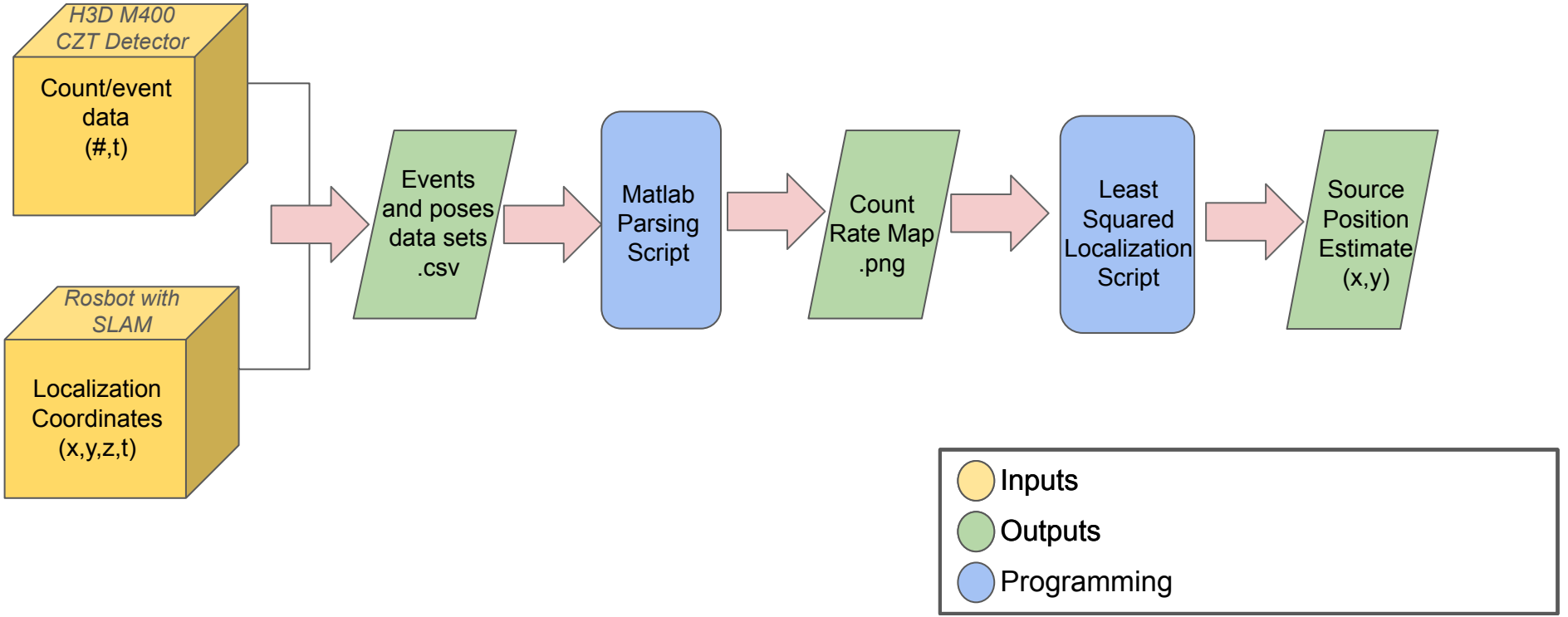
[6]

- Key Takeaways:
  - Image reconstruction precision is improved when the robot is closer to the source.
  - Image reconstruction is improved when the robot moves around the source with a large angle distribution, and it is important to include positions with 90° angles

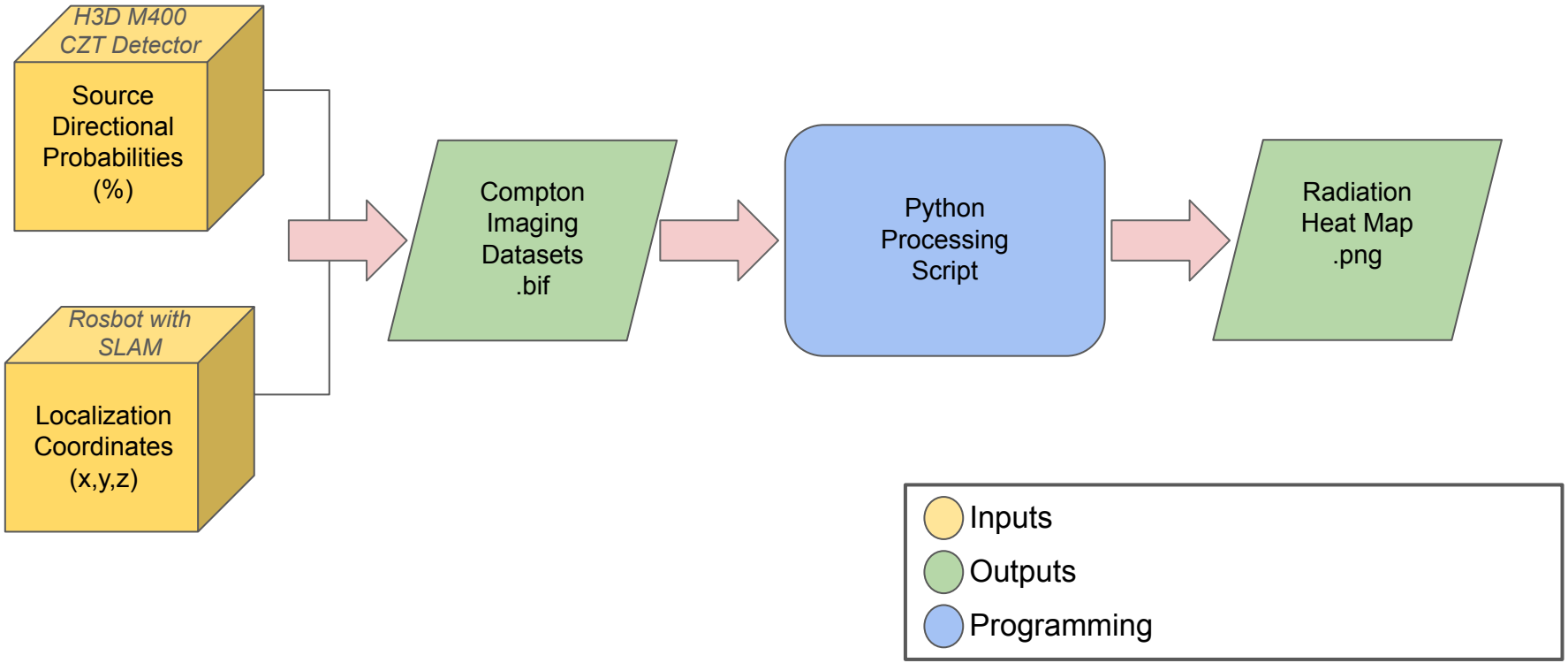
Detector Orientation



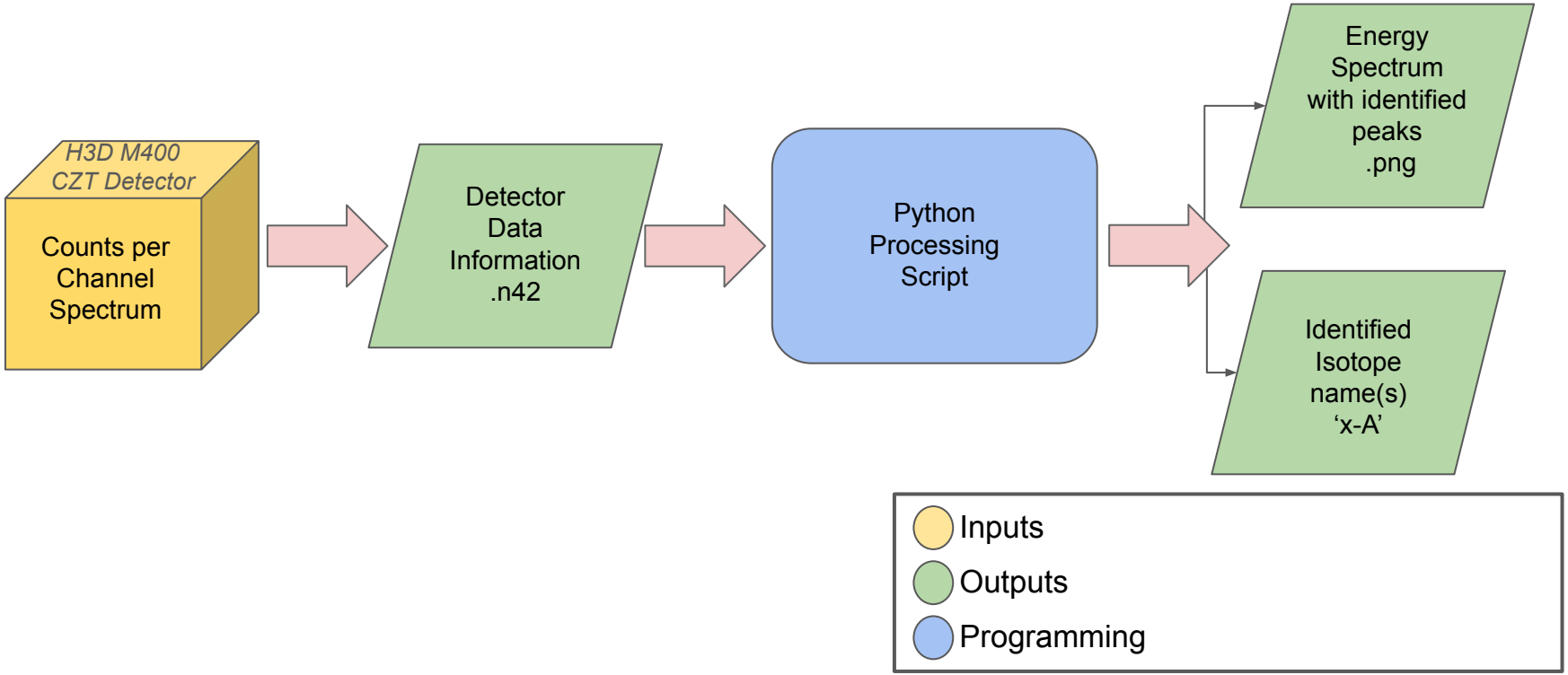
Count Rate Imaging - Data Processing Workflow



Compton Imaging - Data Processing Workflow



Isotope Identification - Data Processing Workflow



Activity Analysis - Data Processing Workflow