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Multiple radioactive sources Localization Method Based on CNN

xul_hnu

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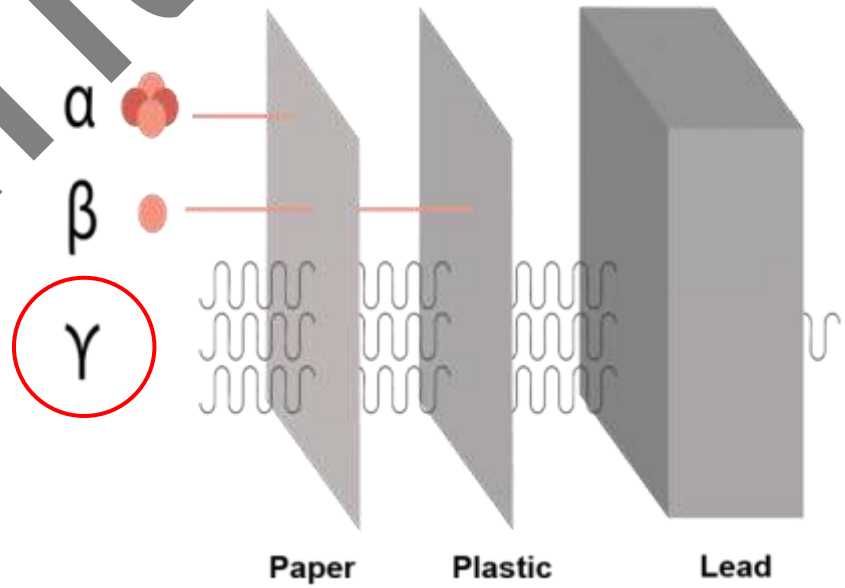
Background

radioactive source

container for radioactive source (lead can)

If the radioactive source is accidentally lost, it will bring a great threat to social security, and may cause mass casualties and serious social panic.



Alpha and beta radiation travel only short distances through air. Gamma rays, in contrast, are highly penetrating and may be detected at large distances from the source.

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Difficulties

The gamma rays emitted by the radioactive source can penetrate the human body, causing great harm to the human body. And the gamma rays can instantly penetrate the semiconductor electronic components, resulting in the paralysis of the robot.

Many methods have been used in the search for a single radioactive source, such as maximum likelihood estimation, particle filtering.

The main difficulties at present are as follows.

- The search for multiple radioactive sources in the environment requires further research.
- Minimize the search time and improve the accuracy of locating the radioactive source.
- Previous methods of searching for radioactive sources have certain limitations in complex obstacle environments.

Radiation-resistant robot

Carry

Radiation detector

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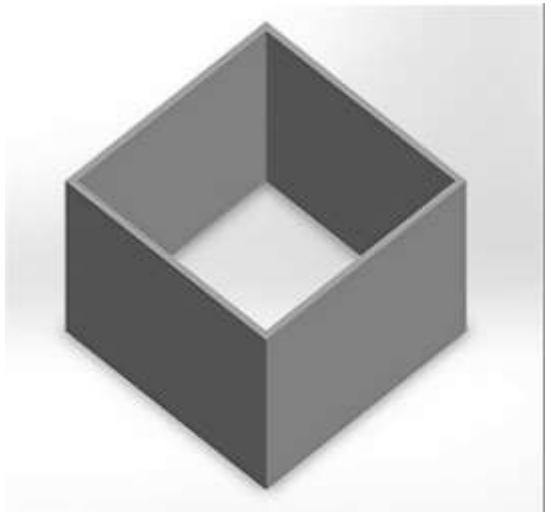
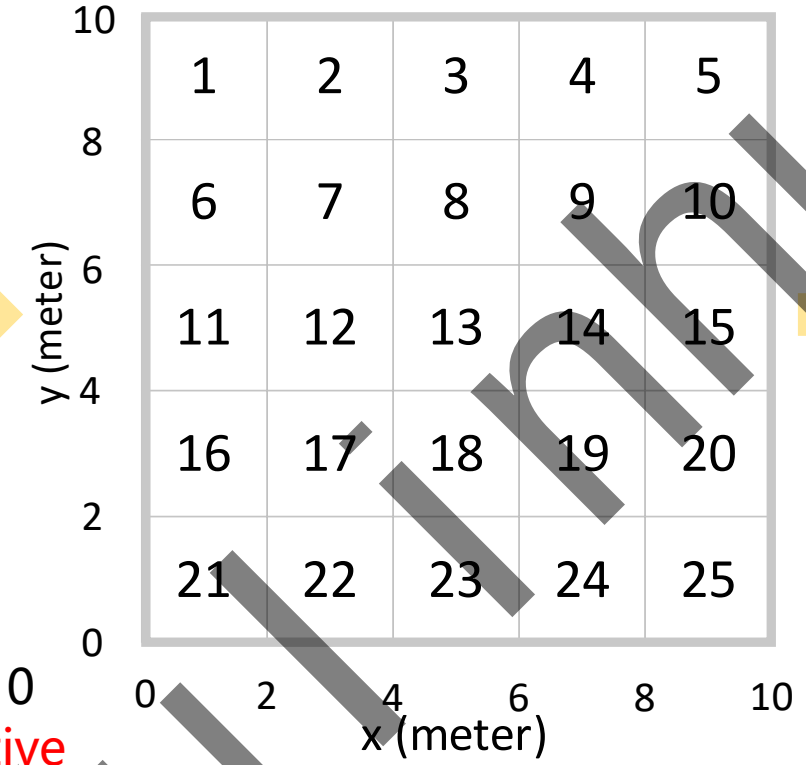
Localization Problem





① There is a room with a size of 10 m by 10 m. There are two radioactive sources of unknown location in this room. The intensity of the radioactive source is the same.

② The floor of the room is divided into 25 small cells (the size of each cell is 2 m by 2 m).

③ each cell is divided into 8 grids by 8 grids (the size of each grid is 0.25 m by 0.25 m).

In theory, the radioactive sources could be lost in any of the 25 units. Usually, the intensity of the radioactive sources can be known in advance. Therefore, the energy deposition distribution or dose distribution of the radioactive sources in the room can be obtained through the Geant4 simulation.

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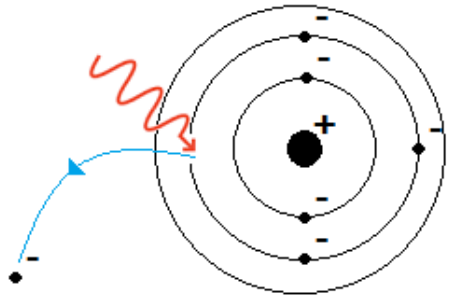
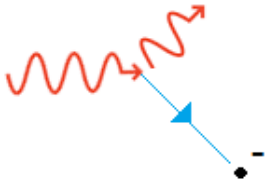
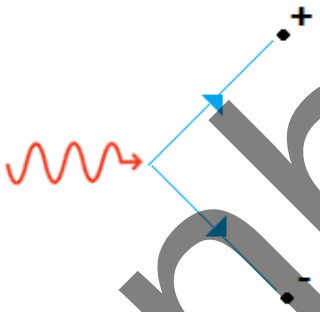
Geant4 Simulation



Photoelectric Effect

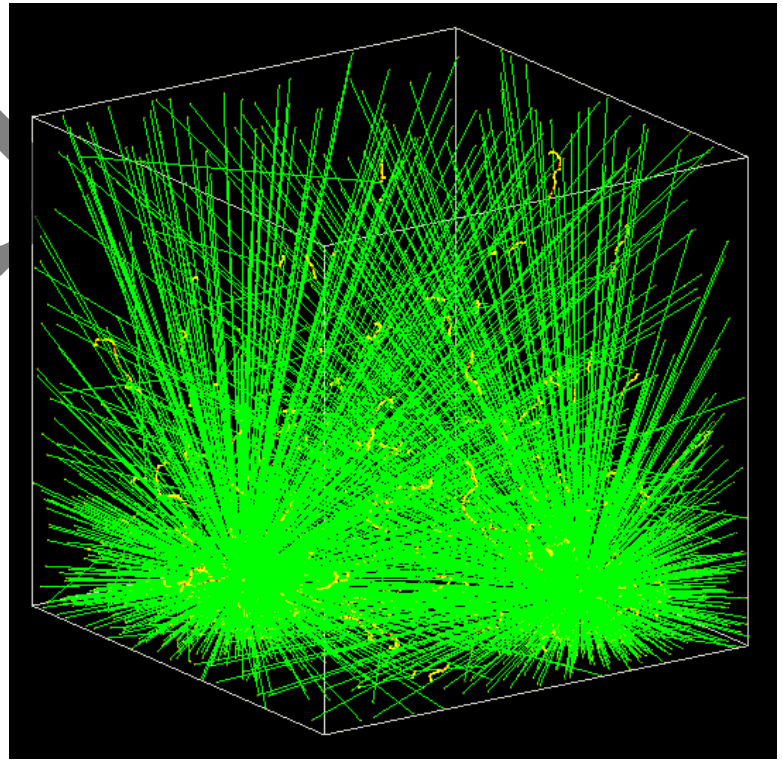


Compton Effect



Pair Production

Incident photons interact with matter



Photons interact with air

- Photoelectric effect: electrons are emitted after a photon strikes an electron outside the nucleus, and energy is transferred to the electron.
- Compton Effect (Compton Scattering): Scattering of photons after they interact with charged particles.
- Pair production: Photons create electron-positron pairs near the nucleus.

The energy of the incident photons is eventually deposited in air or matter. The energy deposition or radiation dose of the radioactive sources in the air can be calculated by dividing the grid in the space.

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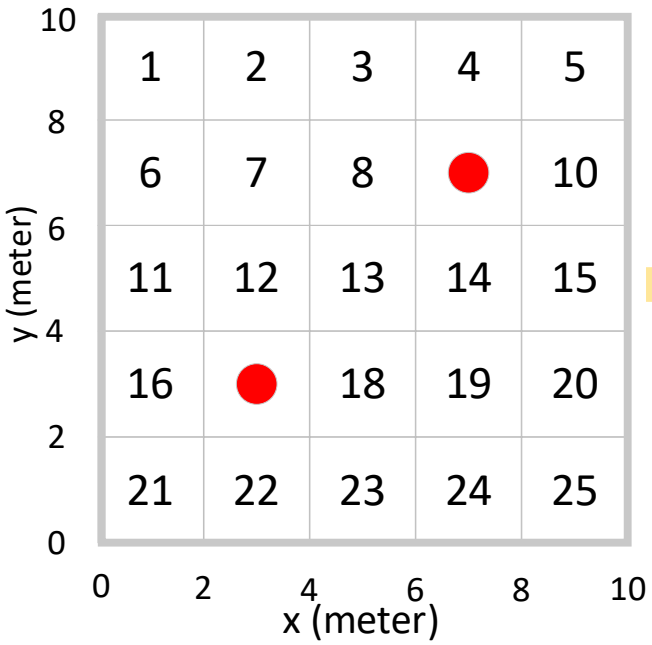
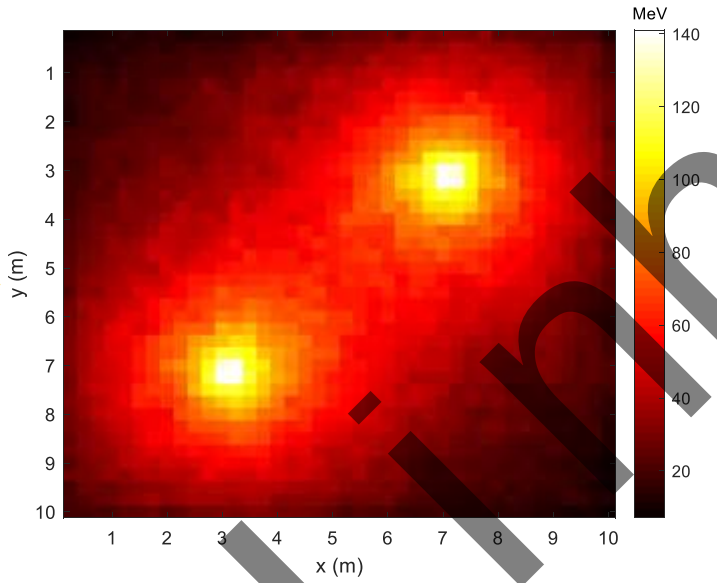
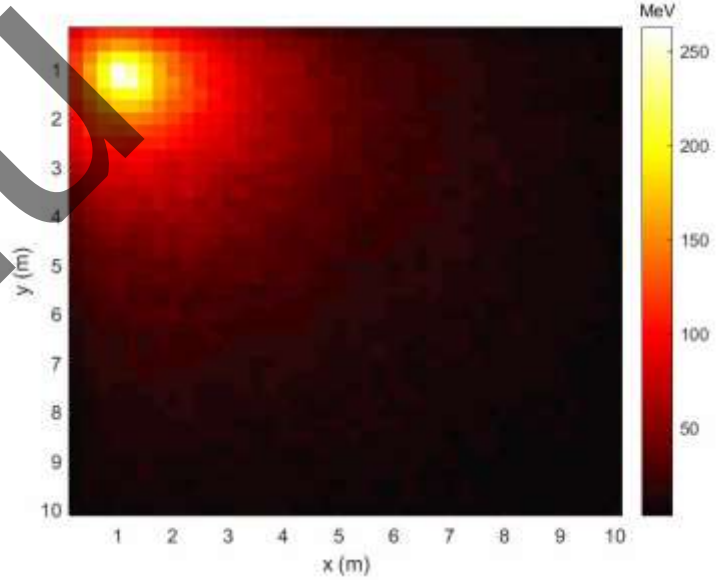
Energy Deposition



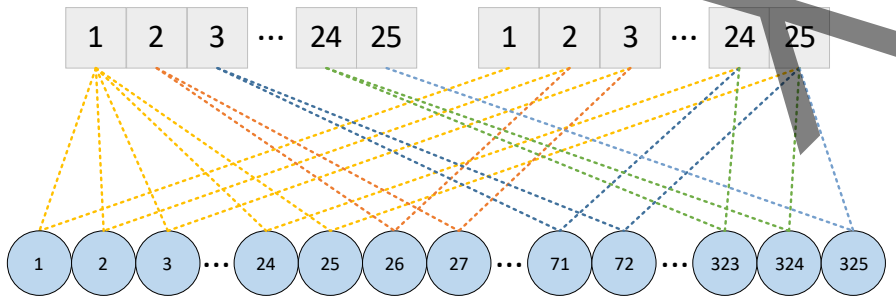
Two radioactive sources are located in the cell 9 and 17, respectively.



The energy deposition distribution of the two radioactive sources is obtained by geant4.



Energy deposition distribution of two radioactive sources at all possible locations in the room



Two radioactive sources may be located in different cells in the room, or may be located in the same cell. There are a total of 325 location classfication.

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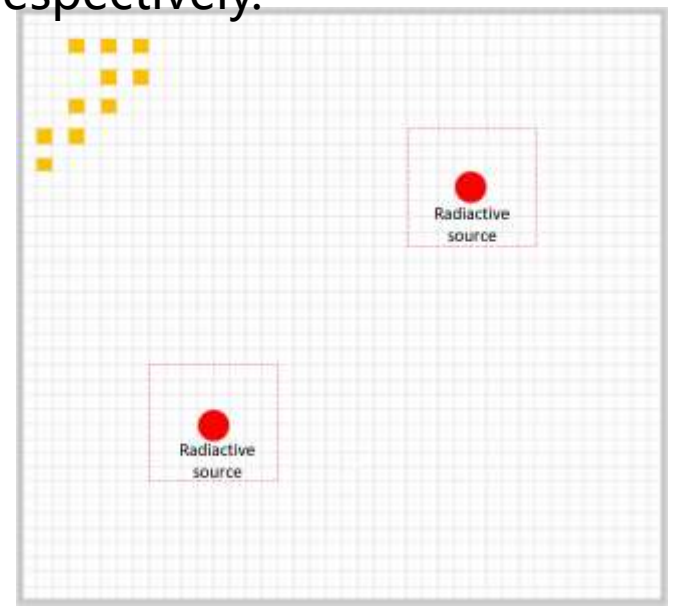
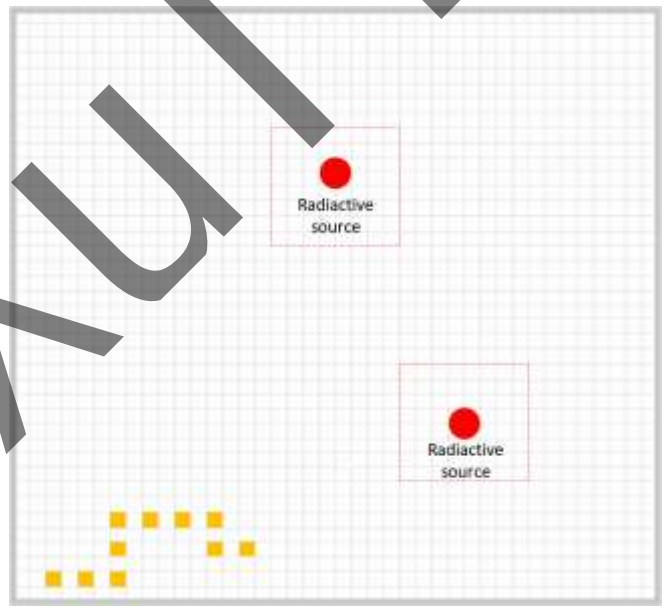
SAW Algorithm

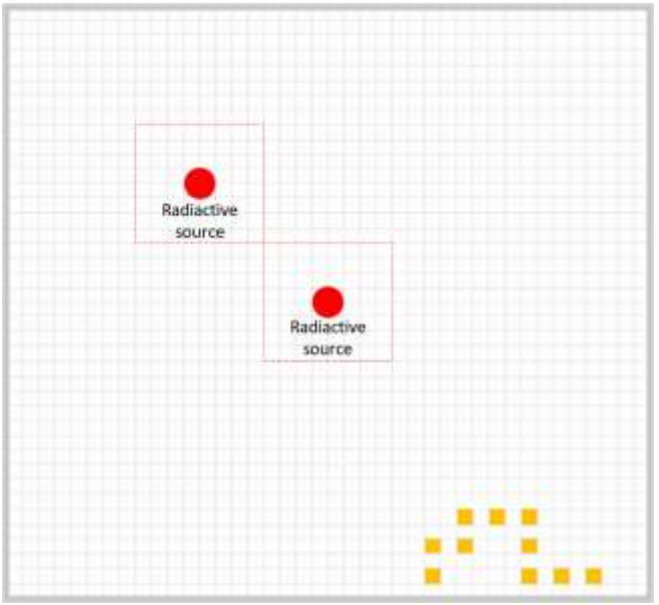
Self-avoiding random walk(SAW) does not repeat the path it has moved before and does not collide with each other. There are mainly the following two SWA algorithms.

- Determine the next position by randomly walking up, down, left, and right. This algorithm is suitable for small step size (less than 15 steps).
- Weighted Importance Sampling. This algorithm is suitable for large step size.

Set the step size to 10 steps and the step distance to 0.5 m (the interval is 0.25 m). Then, generate measurement paths in energy deposition distribution matrix by self-avoiding random walk algorithm. Finally, 1,300,000, 1,625,000, and 1,950,000 measurement path data were generated, respectively.







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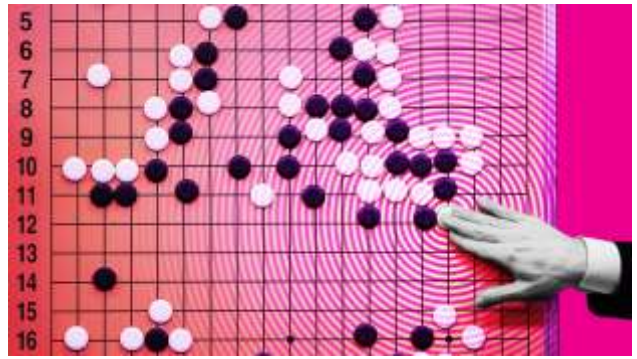
CNN Introduction

Convolutional neural network (CNN) is a kind of artificial neural network, which is often used in image classification and recognition, natural language processing, Computer Vision and other fields.

Image Classification

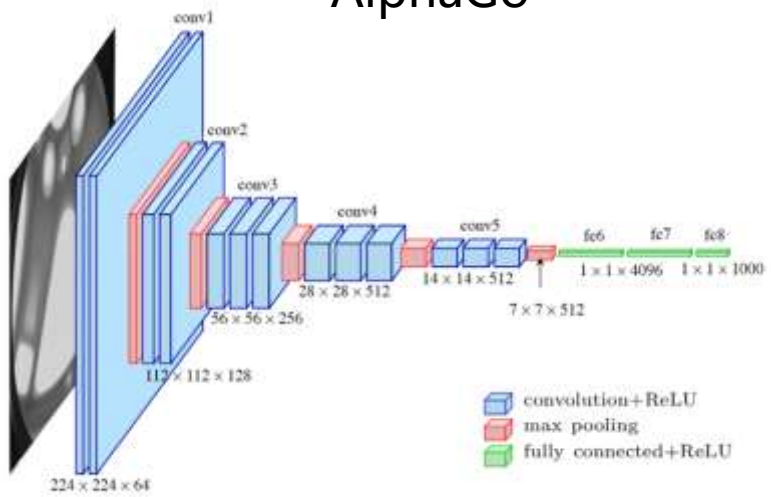
computer vision



AlphaGo

Classical CNN model structures such as LeNet-5 (1989), AlexNet (2012), VGG (2014), GoogleNet (2014) can be used for very large-scale image recognition and localization.

VGG



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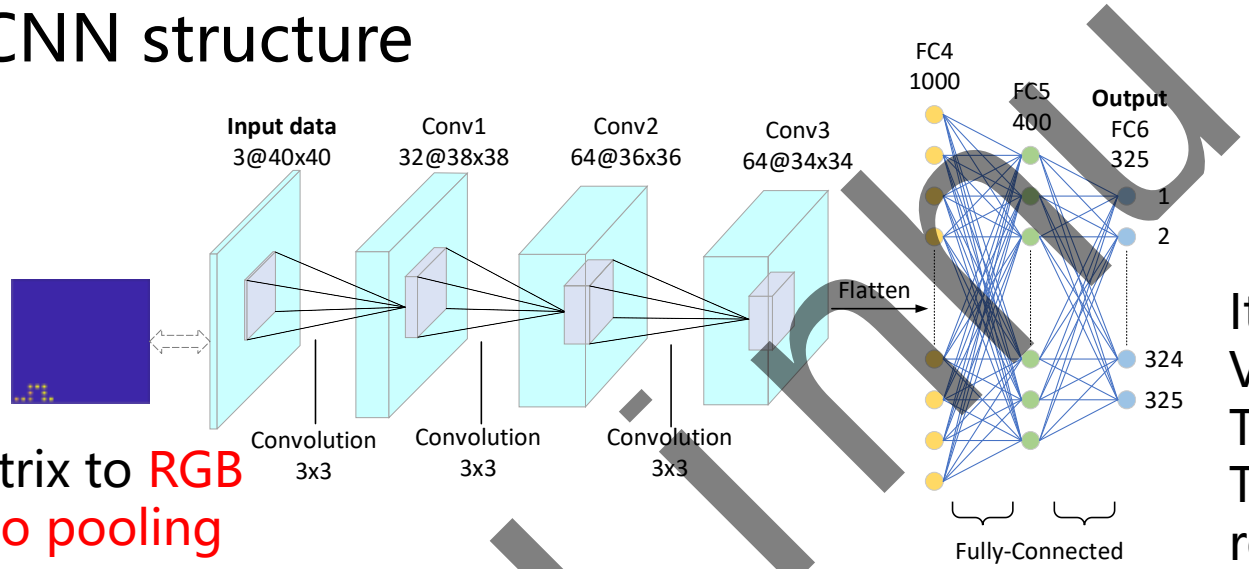
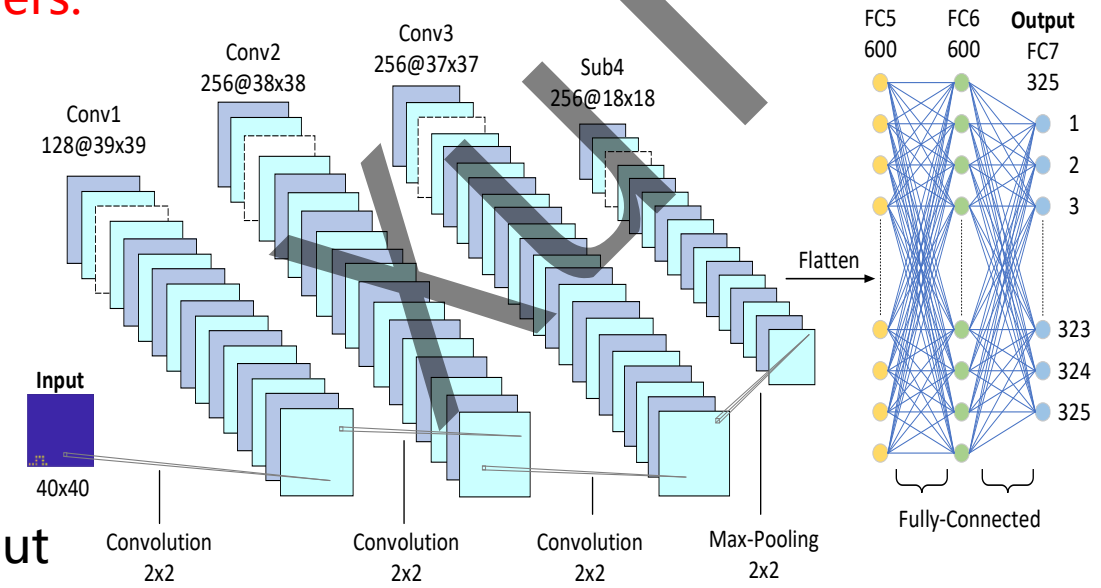
CNN structure

Our designed CNN structure



Expand the input matrix to RGB three channels and no pooling and paddding layers.

It draws on Alexnet and VGG network structure. The training effect is better. The localization accuracy reaches 89%.

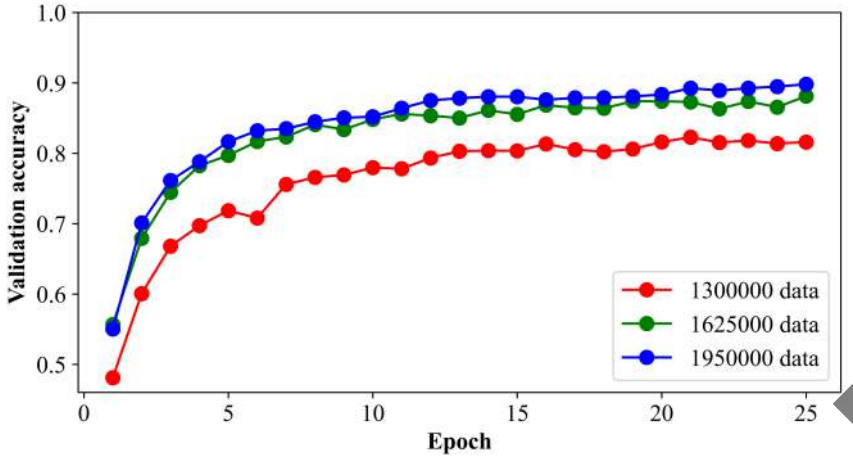


single channel input

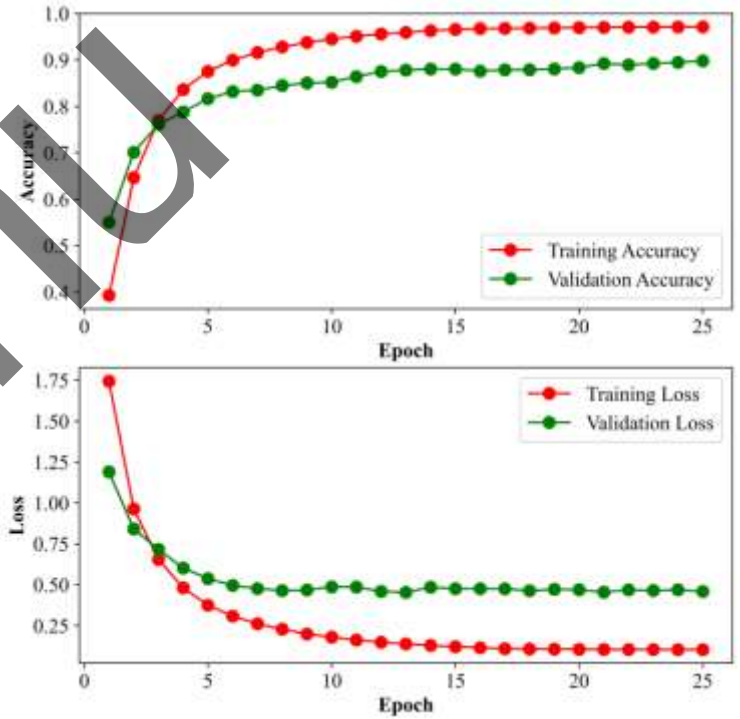
The traditional Lenet-5 network structure has poor training effect. The localization accuracy is only 40%.

Training Results

CNN training results



CNN training results with 10 steps and the dataset sizes are 1,300,000, 1,625,000, and 1,950,000(1.95 million), respectively.



CNN training results with 10 steps and the dataset size is 1.95 million.

Network model performance evaluation

Step size	Dataset size	Precision	Accuracy
10	1300000	0.8159	0.8104
10	1625000	0.8812	0.8811
10	1950000	0.8980	**0.8924**

Input new data into the trained model.Precision represents the proportion of correct detection by the model. Accuracy represents how accurately the model predicts new data.

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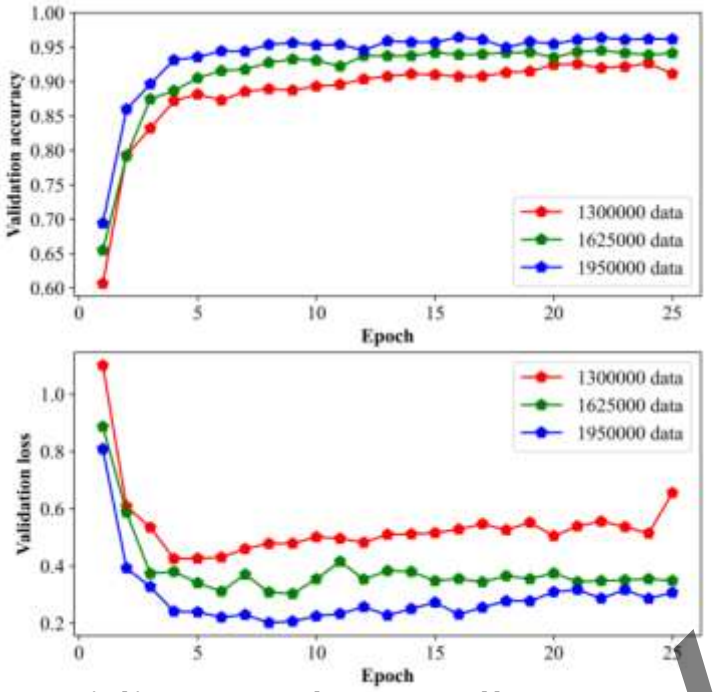
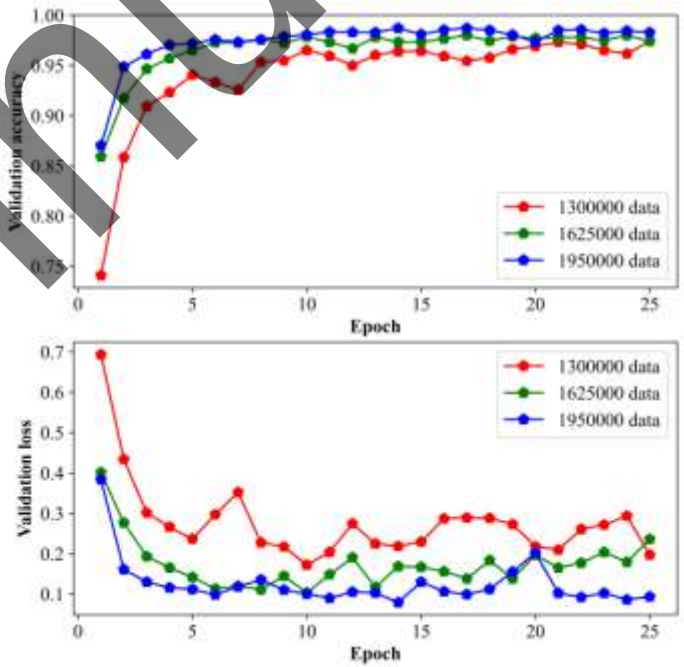
Training Results

Set the random walk path to 15 and 20 steps, respectively



Self-avoiding random walk steps are set to 15 steps.



Self-avoiding random walk steps are set to 20 steps.

Step size	Dataset size	Precision	Accuracy
10	1950000	0.8980	**0.8924**
15	1950000	0.9638	0.9615
20	1950000	0.9870	0.9870

Network model performance evaluation

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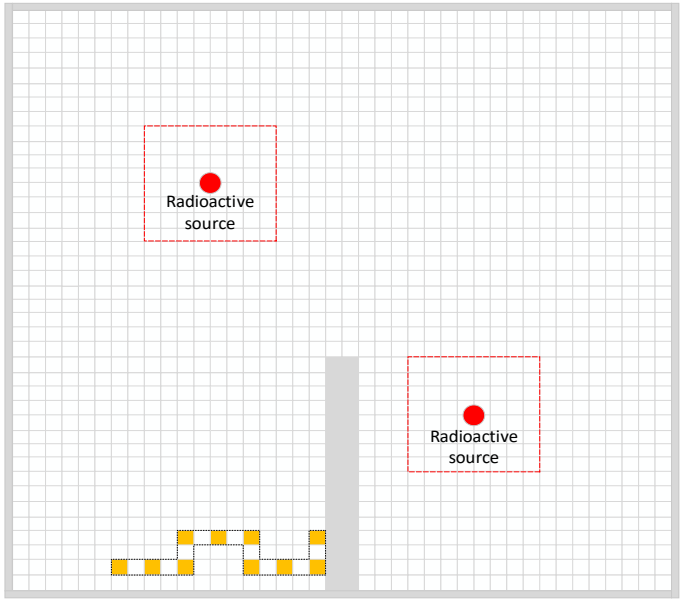
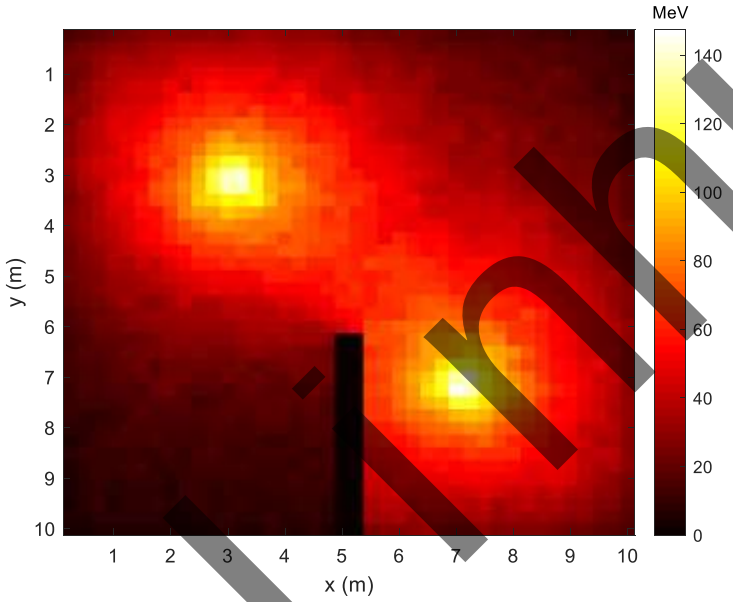
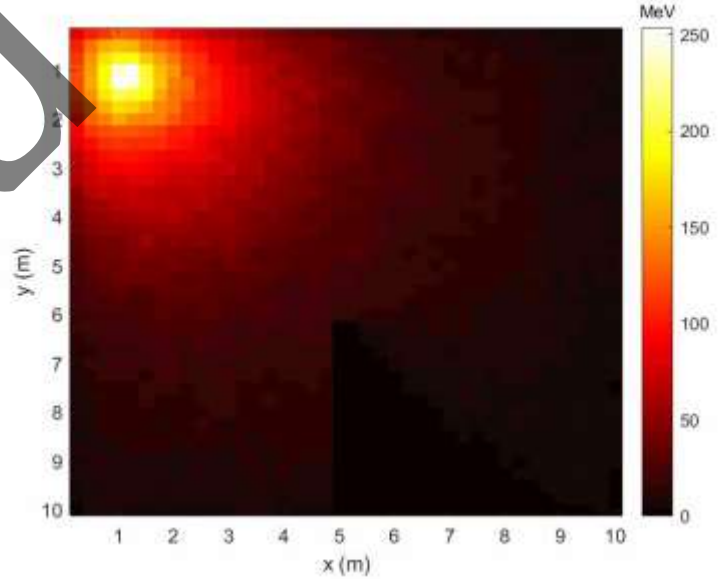
Obstacle Environment







② There is a 4 m long concrete wall in the room, and the random walk needs to bypass the wall (top view).

③ Energy deposition distribution of two radioactive sources in the room.

Energy deposition distribution of two radioactive sources at all possible locations in the room (325 classification).

① There is a concrete wall in the room (3D view)

Likewise, 1.95 million measurement path data are generated through the SAW algorithm. Then input into the same neural network structure for training.

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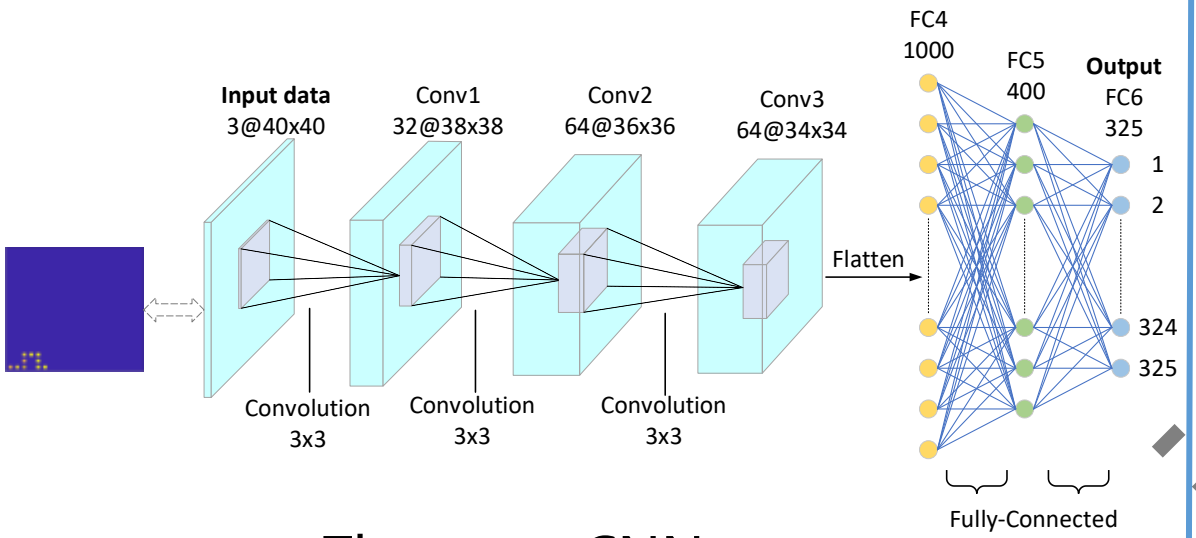
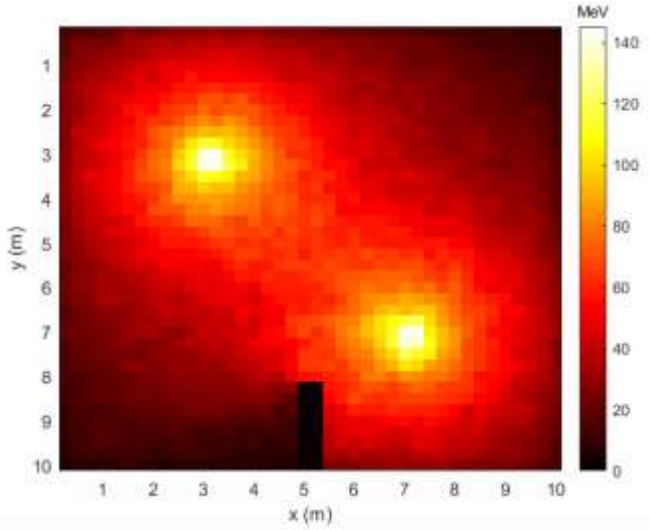
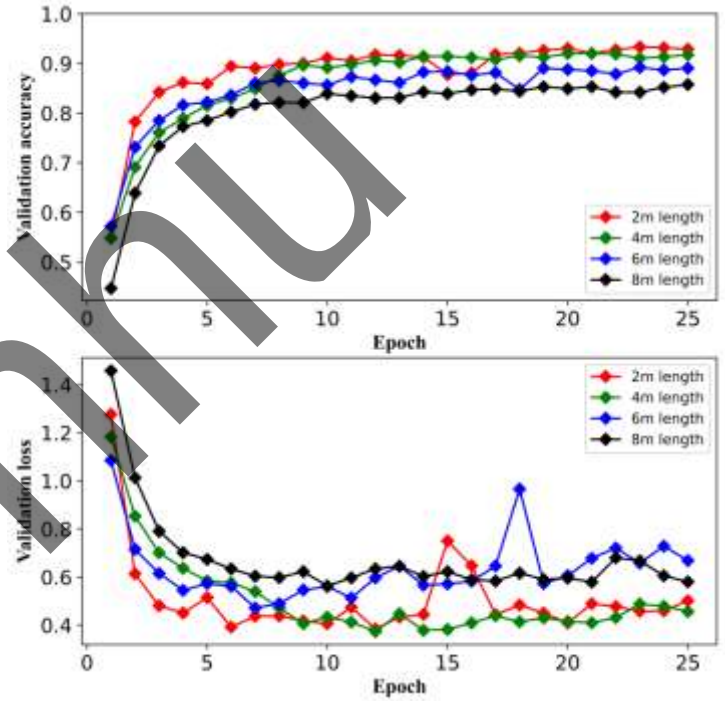
Training Results



The same CNN structure



Concrete walls of different lengths



CNN training results

Network model performance evaluation

One wall	Dataset size	Precision	Accuracy
2 m	1950000	0.9332	0.9289
4 m	1950000	0.9172	0.9103
6 m	1950000	0.8918	0.8904
8 m	1950000	0.8573	**0.8518**

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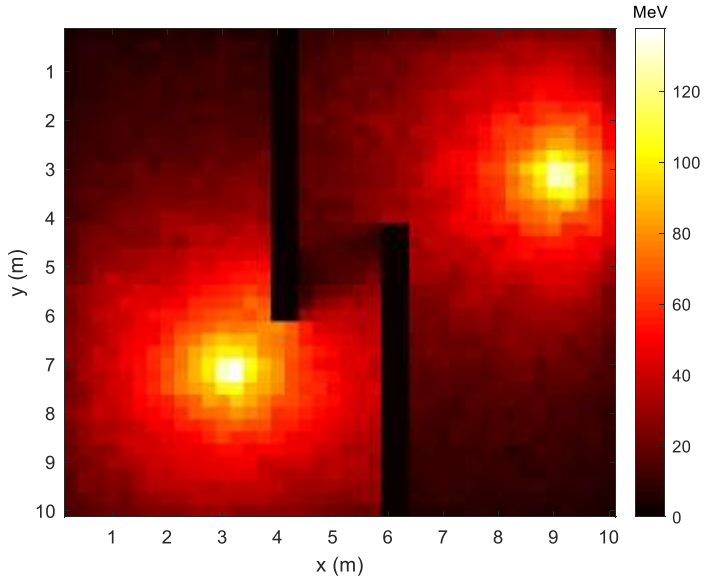
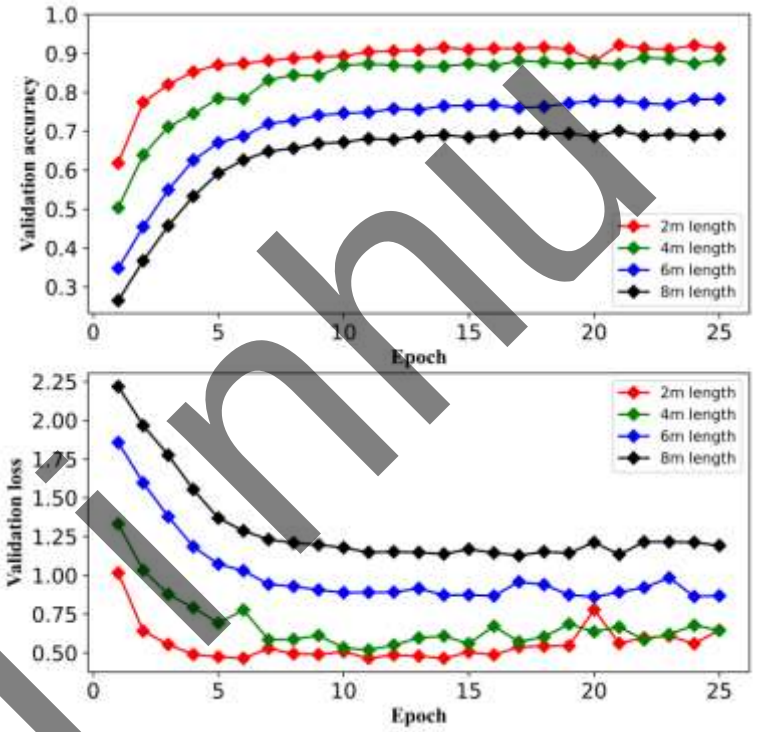
Obstacle Environment



There are two overlapping concrete walls inside the room.

Likewise, 1.95 million measurement path data are generated through the SAW algorithm. Then input into the same CNN structure for training.



CNN training results

Network model performance evaluation

Two walls	Dataset size	Precision	Accuracy
2 m	1950000	0.9205	0.9132
4 m	1950000	0.8890	0.8844
6 m	1950000	0.7995	0.7926
8 m	1950000	0.7010	**0.6860**

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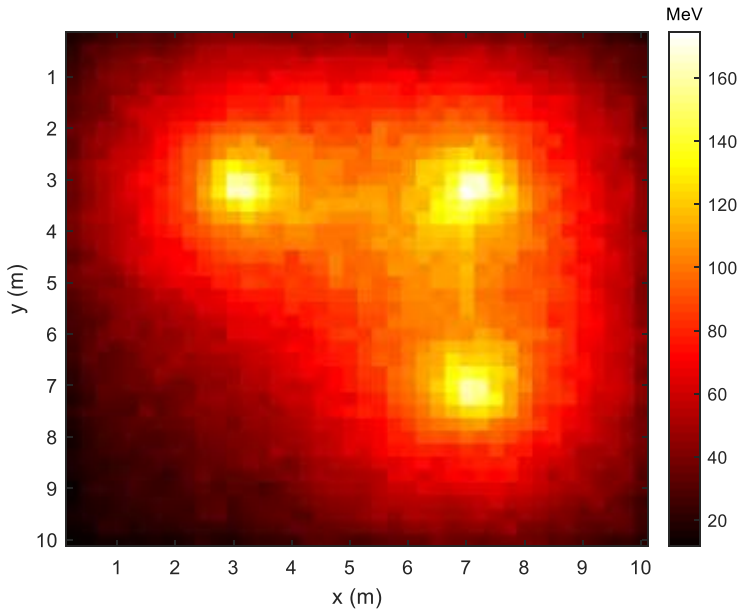
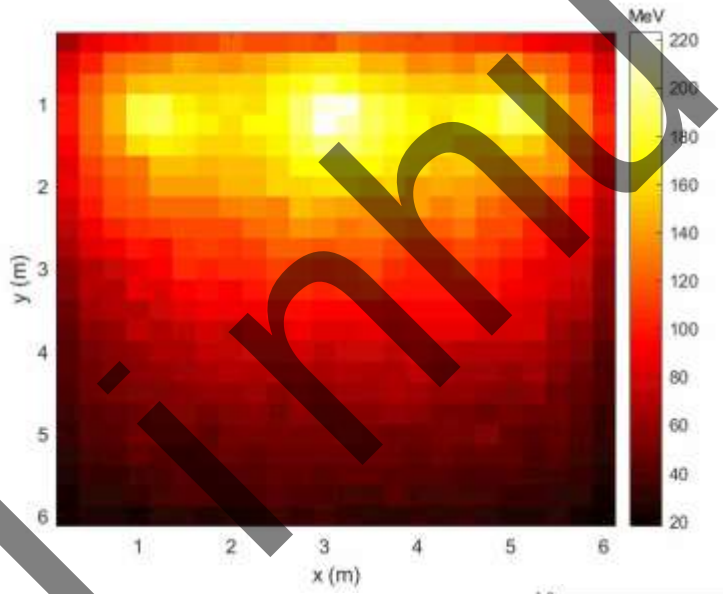
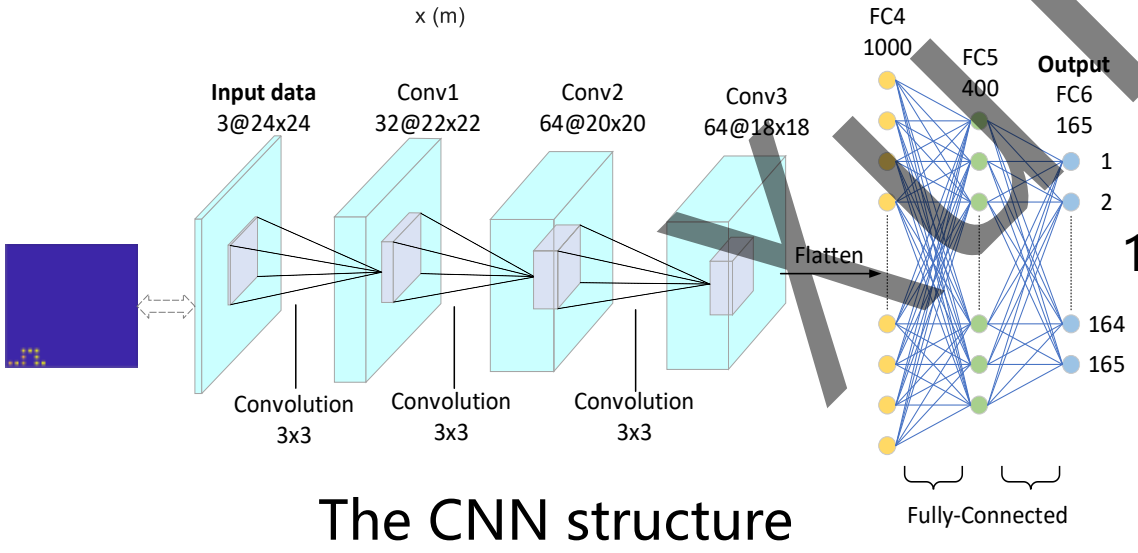
Three γ-sources

The location of three radioactive sources is unknown in the room or area.



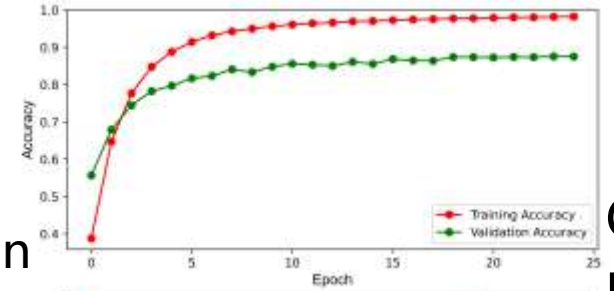


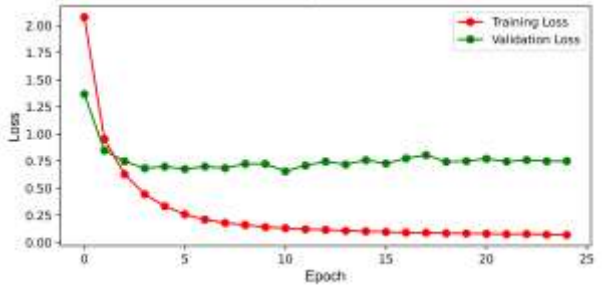
The area is reduced to 6 m by 6 m.Energy deposition distribution of the three radioactive sources (all possible locations in the room or area).



The CNN structure

165 Classification





CNN training results

Accuracy: 84%

Conclusion

- The proposed method can be applied to the localization of two or more radioactive sources. The location of multiple radioactive sources can be predicted in different geometries.only ten times of radiation values are required in the area, and the locations of all radioactive sources in the area can be quickly predicted.

- In the future, we will combine this method with robotics to predict the location of radioactive sources and build radiation maps. And consider real-world application scenarios that are more complex than the simulation environment, including terrain constraints.

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Thank you for listening

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