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Estimation System of 3-D Source Location with Multi-Detector Responses Using Deep Learning Technique

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1. Introduction

When radioactive sources are handled in a restricted area for the use, distribution, and storage facilities of radioactive isotopes, the source locations should be tracked for satisfying safety regulation. In treating high radioactive sources, which is difficult to be directly measured by workers, the tracking of the radiation source locations is one of the issues with considering the radiation-related regulations. Also, the radiation measurement to search unknown locations is time-consuming and increases the worker's exposure. In this study, we demonstrate to find unknown locations of radiation source using the deep learning technique by detecting the fluxes in a room surrounded by concrete walls. The MCNP code was used to obtain the dataset for a given condition. Using the dataset, the machine learning is conducted and the possibility of the source-tracking with the deep learning technique is verified.

2. Methods and Results

For searching the location of the radiation source, a detection system with 9 detectors is constructed. After generating the dataset using the MCNP simulation of the target system, an artificial neural network for predicting the source location is constructed, and the tracking performance of the artificial neural network is verified.

2.1 Generation Condition of Datasets

The Monte Carlo N-particle code is known to conduct accurately simulating radiation shielding and nuclear physics in a three-dimensional geometry. In this study, we set a room for the feasibility study of deep learning technique in searching the source location.

As shown in Figures 1 and 2, it is assumed that the width, length and height of the room are 10 m, 10 m and 2 m, respectively. In each wall of the room, the thickness of the concrete is 20 cm. The centers of nine detectors are installed to 3 x 3 at 190 cm height from the bottom. The type of source used in the simulation was a gamma ray source of Cobalt 60 and the radioactivity was 0.5 Ci.

Table I: Condition of MCNP simulation

	Specification
Type of concrete	Regular concrete [2]
Type of Source	Cobalt-60
Radioactivity of Source	0.5 Ci

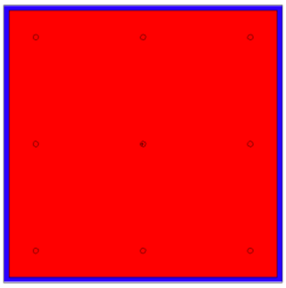

Fig. 1. The appearance of the room structure viewed from a vertical direction

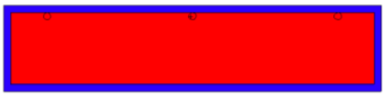

Fig. 2. The appearance of the room structure viewed from a horizontal direction

As shown in Fig 3, it is a three-dimensional room surrounded by the concrete walls. It is assumed that the room is filled by air. For performing the machine learning, the cobalt source were randomly sampled in the room, and the detector responses for each sampled source were recorded. 1,000 datasets including source locations and detector responses were obtained with 4 x 10^6 history per one MCNP simulation.

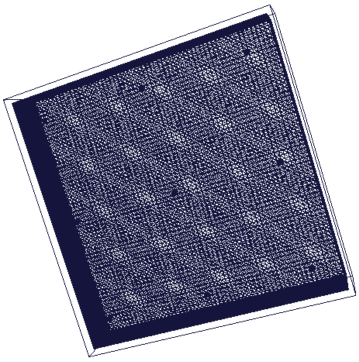

Fig. 3. The appearance of three-dimensional room structure

2.2 Regression Algorithms with Deep Learning

The system proposed in this study is to find the source location from the detector responses given in Sec. 2.1. Therefore, from the nine variables (9 input neurons), we try to predict the source location in space by the XYZ coordinates (3 output neurons).

For constructing the neural network with 5 hidden layers, Tensorflow with ReLU activation function were used [3]. For the machine learning, following cost function was implied:

$$\text{cost}(W,b) = \frac{1}{m}\sum_{i=1}^{m}(H(x^{(i)}) - y^{(i)})^2 \quad (1)$$

where W is weight, b is intercept, H is a hypothesis, y is a result in dataset and m is the number of datasets. In this equation, W and b are continuously changed during the machine learning procedure, and prediction can be used by using the final value. Also, the gradient descent method was used to continuously reduce the error to find the optimized value.

2.3 Results

The number of flux data detected by nine detectors was trained by using 1,000 datasets. In consideration of the problem of overfitting, 1,000 datasets of data were normalized to a number between 0 and 1. In order to increase the accuracy, the artificial neural network was considered thick and 100,000 training sessions were performed. As shown in Fig 4, the step, cost, and learning rate are indicated in order. The final result is the accuracy of the final x, y, and z coordinates when 100,000 training sessions are completed. As a result, it was evaluated that the accuracy is higher than 0.98.

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98000 [3.2765781e-06,  0.00019453507]
98100 [3.21881e-06,  0.00019453507]
98200 [3.3334998e-06,  0.00019453507]
98300 [3.2971136e-06,  0.00019258972]
98400 [3.2951164e-06,  0.00019258972]
98500 [3.3532267e-06,  0.00019066384]
98600 [3.4803795e-06,  0.00019066384]
98700 [3.273735e-06,  0.00019066384]
98800 [3.261691e-06,  0.0001887572]
98900 [3.2656758e-06,  0.0001887572]
99000 [3.2096766e-06,  0.00018686963]
99100 [6.5963795e-06,  0.00018686963]
99200 [3.2072037e-06,  0.00018686963]
99300 [3.1545417e-06,  0.00018500093]
99400 [3.136251e-06,  0.00018500093]
99500 [3.2397847e-06,  0.00018315091]
99600 [3.8487274e-06,  0.00018315091]
99700 [4.2834868e-06,  0.00018315091]
99800 [4.585622e-06,  0.00018131941]
99900 [4.43881e-06,  0.00018131941]

x, y, z Accuracy:  [0.98055166  0.9850989   0.9974523 ]
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Fig 4. Accuracy of the location at X,Y and Z coordinates tested by deep learning technique

3. Conclusions

In this study, we developed a system to estimate the location of the radiation source using deep learning technique with 9 detector responses. The estimation of unknown source location shows low cost and high accuracy. The location of the high radioactive source can be determined even if the person does not measure directly at the use facility. In the future, the study can be applied not only to simple rectangular parallelepiped concrete structures but also to various geometric structures to apply it into the real situations.

ACKNOWLEDGEMENTS

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