Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

A Preliminary Study on Dose Estimator for Radiation Shielding Using Artificial Regression Neural Network

Isaac HAN, Sung Gyun SHIN, Sang Soo HAN, Song Hyun KIM*, and Gun Su YUN

Division of Advanced Nuclear Engineering (DANE),
Pohang University of Science and Technology (POSTECH), Pohang, South Korea, 37673
**Corresponding author: songhyunkim@postech.ac.kr*

1. Introduction

For minimizing the radiation damage in the protective clothing material for workers or patients, lead or lead-based compounds have been widely utilized [1]. The radiation shielding material based on the lead is heavy, and the environmental pollution is severe upon disposal [2]. Recently, polymeric composite shielding materials, which satisfy both convenience and economics, have been studied. For synthesizing polymeric composite, the composite resin is created by mixing materials, and the mixing ratio is modified again to satisfy both radiation shielding performance and productivity. Because this experimental procedure is uneconomic and time-consuming, particle transport simulations such as using the Monte Carlo N-Particle transport code (MCNP) are used before the synthesis of the shielding materials [3]. This procedure also needs large computational cost, so a convenient and efficient method for the estimation of the shielding performance has been required for the developer of the shielding materials. In this study, for efficiently estimating the shielding performance, a dose estimator in developing protective cloth materials for the individual radiation shielding is proposed using a regression model with artificial neural network.

2. Methods and Results

2.1 Data Generation

The target polymeric composite for the radiation shielding material, is a mixture of barium sulfate ($BaSO_4$), bismuth (Bi), tungsten (W) and fiber. As a designing step of the polymeric composite, the composition is not fixed and the atomic density of each material is, therefore, unknown.

To obtain the data for conducting the machine learning, it is assumed that the fibers used in making protective clothing do not affect the shielding performance. Based on the composition boundaries considering the chemical synthesis possibility, 500 datasets were produced using MCNP6 code with mcplib04 cross section library [4]. In this simulation, the 100 keV energy of the X-ray (used in medical diagnosis purposes) was assumed, and the thickness of the shielding was fixed to 3mm for considering the production of the shielding cloth. As a preliminary study of the regression performance, in this study, it was assumed that the effective density of the shielding material is 5 g/cm^3, and mass fractions are only changed as the input variable. By random sampling of the mass fraction for each material, the doses passing through shielding materials were converted by using ICRP116 dose-rate conversion factor. For each simulation, the particle history was determined that the relative error of the response (dose) is under 1 %.

2.2 Artificial Regression Neural Network

Artificial Neural Network (ANN) [5] is one of the machine learning algorithms used in the deep learning technique. ANN can adjust weights through machine learning in a network of nodes. Figure 1 is the schematic diagram of the Artificial Regression Neural Network (ARNN) used in this study.

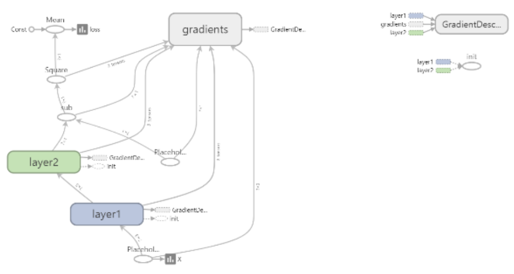

Fig. 1. Schematic diagram of ARNN

For constructing the neural network with 2 hidden layers, Tensorflow with ReLU activation function were used [6]. For the machine learning, following cost function was implied:

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

where H is a hypothesis, x is the dataset value, y is the result given in dataset, and *m* is the number of dataset. With the cost function, the gradient descent method was used as the optimizer. 500 datasets obtained by the MCNP simulations were used to conduct machine learning of ARNN, and 50 additional data were produced to verify the accuracy of the radiation shielding performance of the trained ARNN.

2.3 Results

Figure 2 shows cost values during ARNN machine learning. The costs decreased gradually and converged about 150th step indicating that the machine learning is well accomplished.

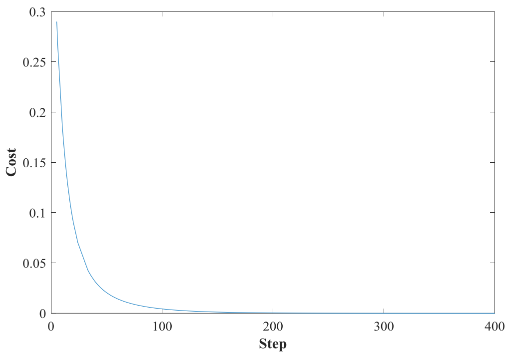

Fig. 2. Cost value at each step of machine learning

Table 1 showed the sampled dose rates estimated by ARNN and MCNP, which were not used in the machine learning. The results estimated by the artificial neural network agreed well within 5 %, and therefore, it is expected that ARNN is applicable for the prediction of dose rates in radiation shielding. In addition, it was verified that the calculation time with ARNN is under 1 s for each calculation.

Table 1. Comparison MCNP results with ARNN results and total accuracy.

$BaSO_4$ [w/o]	Bi [w/o]	W [w/o]	MCNP Results (mSv/h)	ARNN Results (mSv/h)
0.08983	0.08983	0.72295	3.50E-08	3.36E-08
0.04094	0.73470	0.07436	2.60E-08	2.62E-08
0.03688	0.17832	0.63480	2.30E-08	2.31E-08
Total Accuracy of 50 data : 0.963 (relative difference between MCNP and ARNN results)				

3. Conclusions

In this study, the applicability of the ARNN for replacing the conventional particle shielding calculation was tested. A polymeric composite was selected, and dose calculation performance on a specific condition was evaluated. After generating 500 datasets, the machine learning with ARNN was conducted. The results with 50 test sets showed that the ARNN can accurately predict the radiation doses with 96 % average accuracy. The dose estimator with ARNN can dramatically improve the calculation efficiency in the radiation shielding, and therefore, it is expected to lead innovation in the field of radiation shielding estimations.

ACKNOWLEDGEMENTS

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT of Korea (MSIT) (NRF-2018M2C7A1A02071506).

REFERENCES

[1] E. Vano. L. Gonzalez, E. Guibelalde, J.Fernández, J.Ten, "Radiation exposure to medical staff in interventional and cardiac radiology," The British Institute of Radiology, Vol. 71, pp.954-960, 1998.
[2] E. Millstone, J. Russel, "Lead toxicity and public health policy," Perspectives in Public Health, Vol. 115, pp.347-350, 1995.
[3] H. Mori, K. Koshida, O.Ishigamori, K.Matsubara, "Evaluation of the effectiveness of X-ray protective aprons in experimental and practical fields," Radiological Physics and Technology, Vol. 7, pp.158-166, 2014.
[4] Pelowitz, D.B., "MCNP6TM User Manual Version 1.0," LA-CP-13-00634, Los Alamos National Laboratory, 2013.
[5] D.F Specht, "A general regression neural network", IEEE Transactions on Neural Networks, Vol.2, pp.568-576, 1991.
[6] Martin Abadi et al., "TensorFlow: Large-Scale Machine Learning on Heterogeneous Distributed Systems," arXiv:1603.04467, 2016.