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A preliminary study on applicability of artificial neural network for optimized reflector designs

Song Hyun KIM[a,*], Thanh Mai VU[a], Cheol Ho PYEON[a]

[a]*Nuclear Engineering Science Division, Research Reactor Institute, Kyoto University, Asashiro-nishi, Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan*

Abstract

The neutron reflector is a material to reflect neutrons into reactor cores. The reflectors are designed with their one purpose such as increasing the criticality, specific flux distribution, and others. Generally, the reflector design has been conducted by the experiences of designers due to the lots of design variables such as material selection and arrangement. In this study, the applicability of the artificial neural network is preliminarily studied for the optimization of the reflector arrangement. For the research, a system of artificial neural network was developed using C++ program language. The feedforward neural network was used with three layers which are input, hidden, and output layers. The back-propagation algorithm was adopted for the training of the neural network. After the construction of the neural network system, the optimization and auto machine learning algorithms was developed by C++ programing language for the preliminary study on the applicability of artificial neural network into the reflector design. The results show that the reflector gives a good performance to obtain the goal responses. It is expected that this system can contribute to dramatically increase the efficiency of the reflector designs.

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Keywords: Artificial Neural Network; ANN, Reflector Design;Fuel Pattern; Arrangement, Optimization; Nuclear Reactor; Criticality;

* Corresponding author. Tel.: +81-72-451-2604-; fax: +81-72-451-2604
E-mail address: kim@rri.kyoto-u.ac.jp

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1. Introduction

Reflector is a material which is used for reflecting neutrons generated from the fission reaction of nuclear reactor core. The reflector is used for increasing the efficiency of neutron utilization for the fission chain reactions in reactor core. The graphite, beryllium, steel, water and the others can be used as the reflectors with their one purpose. In research reactors, the various reflectors can be selected and used for their experiment purposes. The reflectors are conventionally designed and arranged by depending on the experiences of the designers. These empirical approaches can cause efficiency problems because it is required to perform lots of estimation trials on their proposed designs and arrangements based on the human experiences. To replace these kinds of human works, artificial neural networks (ANN) has been attention during last decades for lots of fields. The ANN is a virtual algorism developed by imitating human brain neural. The ANN has strength on that it can deduce the prompt answer from arbitrary input, and automatically increase accuracy without any mathematical foundations.

In 1943, a basic idea of the ANN was proposed by Warren McCulloch [1]. They defined the artificial neurons and a cell model with the concepts of weight and activation function. To learn a simple ANN, Frank Rosenblatt introduced a perceptron in 1958 [2]. Using the perceptron theory, the weight, which has a function of brain memory in ANN, is trained and for linear separable problems. The single-layer neural network had a limitation to solve non-linear problems. In addition, lots of transport problems are generally non-linear problems. Therefore, an advanced method should be used for the transport analyses. It was verified that these non-linear problems can be solved with multilayer neural network and backpropagation model. The multilayer neural network is a neural network having more than one hidden layer called feedforward neural network. Generally, this neural network has input layer, hidden layers and output layer. One hidden layer can express all continuous functions and two or more hidden layers can express the non-continuous functions. For the machine learning of the neural network, more than 100 methods are known. The most popular method is the backpropagation method proposed by Bryson and Ho [3]. After those of researches, a lot of methods have been developed to increase the efficiency of the machine learning and accuracy of the neural network.

For the nuclear research field, the application of neural network theory is in a beginning step, and some researches related to the ANN have been notified. In the previous studies, the ANNs are used for the PWR design of core reloading pattern [4-6]. The applications of ANN in these reactors have been used focusing on the loading pattern and design parameters of nuclear reactors. These are generally applied for fixed core configurations, and it can be easily analyzed with the small number of core variables. Also, it has some limitation because the NAA was just used for the data analysis. In cases of research reactors, the core configurations and arrangement including the reflectors and moderators can be significantly changed with their purposes. Due to the core configurations, it has been required lots of the human efforts on its design.

In this study, the applicability of ANN for the design of research reactor core focusing on the reflector arrangement is studied. First, a multilayer neural network was programed with C++ programing language. Using the ANN program, an automatic machine training algorithm was also developed for the reflector designs with MCNP6 code.

2. Method

2.1. Overview of feedforward neural network and back-propagation algorithm

The flowchart of the feedforward neural network used for this study is given in Fig.1. k_{eff} is set to the goal output for the possibility study of the ANN. There are three layers which are input, hidden and output layers. When a material selected from m candidate materials in each region is decided as an initial condition, the input neurons, which is matched to the material number of the region in input layer, is set to 1. At the same time, the other input neurons linked with the region is set to 0. The input signals are linked to the other neurons with weights. For the estimation with the ANN, first, the weighted input is calculated with Eq. (1).