Development of deep learning for predicting reactor internal phenomena in severe accident

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1. Introduction

Severe accidents such as Fukushima nuclear accident may unexpectedly occur in nuclear power plants (NPPs). Severe accident is that the accident condition is more severe than a design basis accident (DBA) with involving significant core damage due to core melting. The multiple safety systems including high pressure safety injection (HPSI), low pressure safety injection (LPSI), safety injection tank (SIT), and etc. have been designed to protect the core under the accidents in NPPs [1].

If the decay heat from reactor is not removed due to the failure of safety systems under the accidents, the core can be melted. Therefore, the monitoring of reactor internal phenomenon is very important to prevent core meltdown. However, an instrument for monitoring of the reactor internal phenomena is vulnerable to high temperature and predicting the reactor internal phenomena using physical model takes a long time. We have developed a suitable instrument for high heat. And the developed instrument will be installed on the outer wall of reactor. This can withstand the high heat and accurately provide the valuable information. The deep learning model can be simulated for reactor internal phenomena without knowledge of physical.

Deep learning is one of the most active research fields in recent years because computer's performance has been improved. It has been widely used not only in science but also in various industries such as medicine, advertising, and finance [2].

Deep learning is a technology that applies information processing methods of human brain to machines. The basic structure of Deep learning has a multilayer perceptron (MLP) structure consisting of three or more hidden layers. The MLP is a neural network composed of several nodes and layers. The basic structure of a neural network is divided into an input layer, a hidden layer, and an output layer. The input layer receives input signals. The hidden layer adds all incoming signals to node. Then, the activation function transfers the input signal to the next node, if it is above a certain value. The output layer outputs the result of the model.

In this study, a deep learning model was developed to predict the reactor internal phenomena under the station blackout (SBO) using thermal distribution data of vessel cylinder. The acquired data only considered safety injection by SIT without HPSI and LPSI operations. The location of data is as follows: The thermal distribution of core cell, core baffle, bypass, support barrel, down comer, and vessel cylinder. The data was obtained by using MELCOR which is the severe accident analysis code.

2. Methods and Results

2.1 Method

The convolutional neural network (CNN) architecture, an example of a modern deep learning architecture, is a multilayer node of convolution operations which compute non-linear input transformations. The CNN model consists of learning weights and biases very similar to general neural networks. The hidden layer structure of CNN is divided into convolutional layer, pooling layer, activation layer, and fully connected layer such as figure 1.

The characteristics of the data are extracted by the convolution layer. The pooling layer is sub-sampled. That is, it extracts better characteristics from the data through the convolution layer. Activation layer adds nonlinearity to network using activation function. The fully connected layer combines all previous inputs and outputs the result.

Each operation in the node transforms its input in a manner that increases the selectivity and uniqueness of the output representation. The flexibility of deep neural networks allows models in principle to learn successively higher orders of features from raw data, making the application of deep learning models in physical phenomena highly attractive [2].

There are already several examples of note exploring the application of deep learning techniques within the physics and engineering communities, including applications for accelerating fluid simulations in graphics generation and shape optimization for drag reduction. While previous approaches have shown deep learning models perform exceptionally well in classification and regression tasks, we show that deep learning models are also effective at generating realistic samples from arbitrary data distributions [3].

In this study use the CNN-based U-net model. The U-net architecture uses a convolution network for the encoder and upsampling for the decoder. Figure 2 shows the U-net architecture. Data of upsampling layer is generated by multiplying the input data with the filter of the convolution. The concat layer is connected by coping and cropping the encoder data to ensure accurate localization. The output of the model is generated similar to the target data. The generated output data by the model is compared with the target data. If the output data of model is not similar to the target data, the model will continue learning and output the optimized output value. [2]

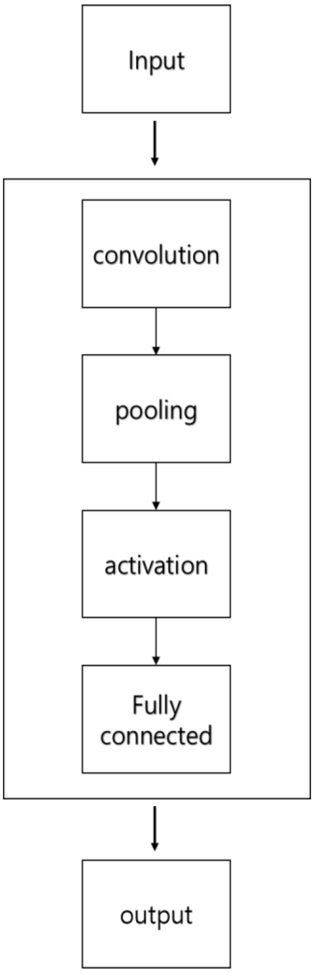

Fig. 1. Convolution Neural Network

2.2 Results

The target data is the thermal distribution of core cell, core baffle, bypass, support barrel, down comer, and vessel cylinder. The target data was obtained from the MELCOR code. We can get information about the thermal distribution of vessel cylinder through the developed instrument. The developed U-net structure is predicted the reactor internal phenomenon by the temperature distribution of vessel cylinder without physical equation.

3. Conclusions

Severe accident is occurred by an unexpected accident at the plant or when failed the safety injection system under the DBA. In this study, model was developed to predict the reactor internal phenomena with the thermal distribution of the vessel cylinder. The operators can maintain the integrity of the reactor when an unexpected severe accident is occurred in the nuclear power plant because the developed model can predict the reactor internal phenomena by the thermal distribution of vessel cylinder.

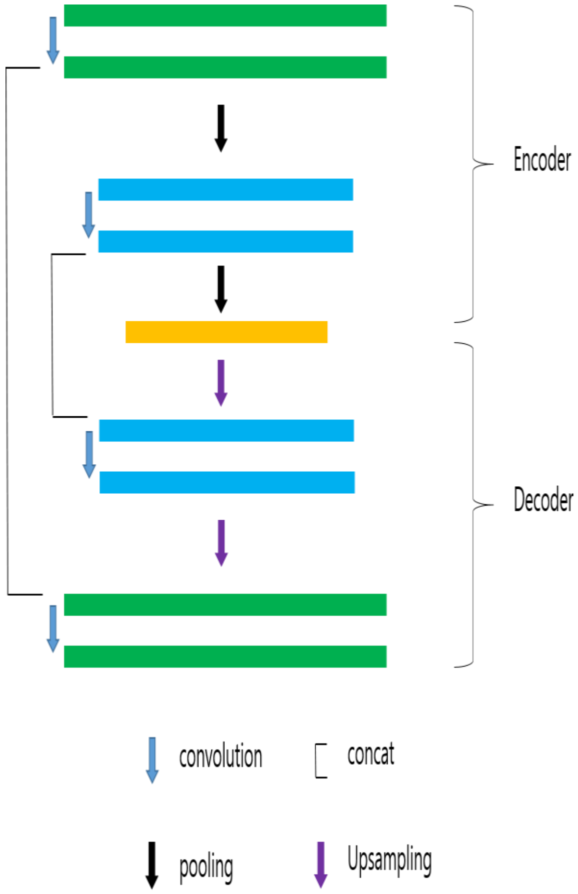

Fig. 2. U-net model

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