Considerations on Data Mapping of Convolutional Neural Networks to Diagnose Abnormal Status in Nuclear Power Plant Operation

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1. Introduction

When abnormal event occurs, operator should diagnose the plant status to decide the response operation which is required to mitigate the effect of the event. There are over 80 procedures for each abnormal status and each abnormal procedure has more than one cases of that abnormal status. Every case of abnormal procedure has its own cause of abnormal status, list of alarms, plant variable conditions. Operator should be trained to diagnose the case of abnormal status to maintain the plant safe. However, due to various abnormal cases, operational mental workload to keep knowledge for diagnosis is relatively high. To reduce the mental workload, operation support system based on artificial intelligence needs to be developed.

2. Convolution Neural Network

Deep convolutional neural networks (CNN) have been widely and successfully applied for image classification [1-3]. A CNN consists of multiple layers such as convolutional layers with activation, pooling layers and fully connected layers. The combination of convolutional layers and pooling layers extract the main features of image and generate feature map. The fully connected layers classify feature map to generate output. The CNN have led breakthrough in various field not only in image classification. So, CNN also can be applied for diagnosis of abnormal status in nuclear power plant operation. The CNN has been reviewed and some considerations have been founded to apply CNN to diagnose abnormal status.

2.1 Convolution and pooling effects

The difference between normal deep neural network and CNN is data processing which are convolution and pooling. For image classification, the important characteristic features such as edge of target object in the image should be extract. The image has many pixels and some of pixels are important for the extraction of characteristic feature and some are not. Convolution and pooling effectively emphasize the data which is required and ignore the data which it not required for classification. Figure 1 shows typical image processing after convolution and pooling of CNN with MNIST which is handwritten digit image database for machine learning research [4].

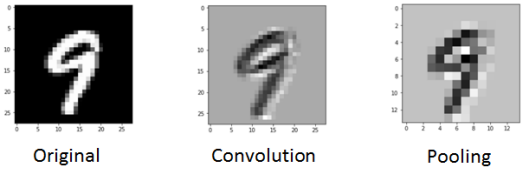

Figure 1 Typical MNIST image processing in CNN

For the diagnosis of abnormal status, the CNN image processing may have pros and cons. In abnormal status, a few of data changes may represent the status, therefore the changes should be extracted and emphasized. The convolution and pooling may extract the changes when proper parameters are applied. However, during the process some data are ignored or diminished. Therefore, the sensitivity test is required to verify the effect of the CNN and to find proper parameters.

3. Abnormal status data generation

To develop efficient and meaningful convolutional neural network, the size of data for learning is important. Unfortunately, there isn't enough data for abnormal operation in real plant. For Shin-Kori unit 3, there is less than 10 cases of abnormal operations during one year of operation. Digital twin is used to generate data when there is limitation of data in real world. In nuclear power plant there is simulator which can be used as digital twins to generate abnormal plant data. In nuclear power plant, for major expected abnormal status, abnormal operation procedures are provided which include scenario of the abnormal state. The abnormal operation data can be generated based on the scenario with variations for enough number of data.

4. Data mapping methodologies for convolutional neural networks

Convolutional neural network is developed for image classification. The strength of the CNN is image processing through multiple layers which are based on two dimensional data map. The abnormal plant data is not two dimensional data like image. It is series of plant

variables such as temperatures, pressure, neutron flux and radiation, Therefore, the order of data should be decided to generate operation data for CNN learning and the order may affect to the accuracy of the CNN. There are following considerations for the order of data matrix (characteristic map generation). 1) Two-dimensional arrangement based on the location and type of data, 2) Number and configuration of characteristic map, 3) Normalization algorithm. Figure 2 shows the basic concept of the CNN application to plant operation data.

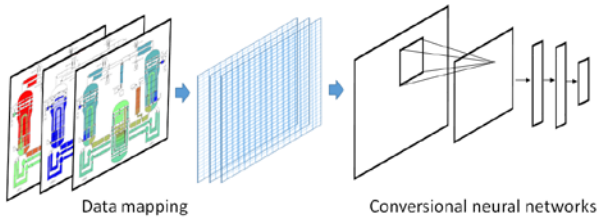

Figure 2 CNN application to plant operation data

4.1 Two-dimensional arrangement based on the location and type of data

Operation data can be formatted as characteristic map according to the two dimensional position of detected location. Traditionally, in thermo-hydraulic analysis, vertical mapping of the reactor coolant system is used for modeling. Some characteristics such as temperature or pressure can be modeled as two dimensional map. Empty location of the map can be filled as zero according to "padding" methodology in the CNN. Characteristic map can represent the status of operation well because that abnormal status may occurs locally at first.

4.2 Number and configuration of characteristic map

There will be more than one mapping to represent plant status. However, the number of map should be limited to avoid the curse of dimensionality [5]. There are overall characteristics such as temperature and pressure can be modeled as one map. However, some characteristics such as neutron flux and radiation is locally detected, so it can be applied to only some part of characteristic map. To reduce the calculation, some characteristics should be small map or immerged into one map. The way of configuration will be selected according to the sensitivity test.

4.3 Normalization algorithm

The range of plant variable is various. For the diagnosis accuracy, the data in characteristic map should be normalized. If the data is not normalized, the data with small variation may be ignored during calculation. The typical normalization methodology is the division of each value with maximum value. The maximum value can be obtained in many ways and one is from the range of the variable during normal operation in simulator or plant. However, in abnormal or emergency status the range of the variable may exceed maximum value of normal operation. So, if normalization applied maximum value in normal operation, the abnormal status may have a value which is not normalized. The effects of non-normalized value also need to be tested. Another proposed normalization is subtraction with average normal plant value before division with maximum value.

5. Discussion

There are many algorithm in artificial intelligence model. The CNN is one of promising algorithm for diagnosis of abnormal status. The characteristic of CNN and considerations on applicability has been reviewed. The proper parameters for convolution and pooling in CNN to diagnose abnormal status are need to be defined. The data mapping methodology to represent abnormal status efficiently is also need to be defined. The sensitivity test is planed according to the proposed considerations. Followings are major factors for the accuracy. 1) Degree of abnormality, 2) Type of abnormal status (affected variable range), 3) CNN parameters, 4) Characteristic mapping configuration, 5) Normalization methodology, 6) Number of learning data.

One of additional discussion item is the changes of plant status according to the time. Proposed methodology with the CNN is bases on snapshot of plant status. However the changes of plant status is also important characteristic of abnormal plant status. When the sensitivity test has been completed, the necessity of application of status changes should be reviewed.

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