Development of Convolutional Neural Networks to Diagnose Abnormal Status in Nuclear Power Plant Operation

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1. Introduction

Recently, there are researches to apply artificial intelligence for diagnosis of abnormal status in nuclear power plant [1, 2]. The main idea of these researches are training neural network to classify plant status. There are about 200 abnormal status which is prepared in abnormal operating procedure. However, there are limit of abnormal events history in real plant. Therefore the development strategy are required to overcome the lack of event history.

2. Consideration for data preparing for training

The simulator is used to generate various abnormal operation data. The simulator should have enough fidelity to express the abnormal event. Even there are differences between simulation data and real plant data, the overall plant dynamics are simulated enough to be used as training data for neural network. Fig. 1 shows the simulation data and plant data for normal operation. Most of variables has similar values.

Fig. 1 Simulation data and plant data for normal operation.

Fig. 2 shows the trends of major operating variables for feed water pump trip from simulation and real plant operation history. Solid line graph is for simulation data and the dotted line is for plant data. There are differences at the level and detail changes between simulated and plant data, but the dynamics of variables show enough fidelity to be used as training input to neural network.

Every abnormal event should be simulated with various scenario. For example, when there is leakage at a valve, the amount of leakage should be varied. The simulation data should be generated from small amount of leakage to large amount of leakage.
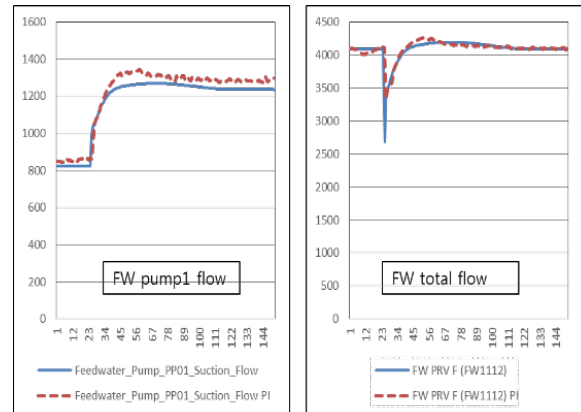

Fig. 2 Simulation and Training configuration for abnormal status diagnosis

Fig. 3 show the training configuration for abnormal status diagnosis. Convolution neural network is used to train abnormal status.
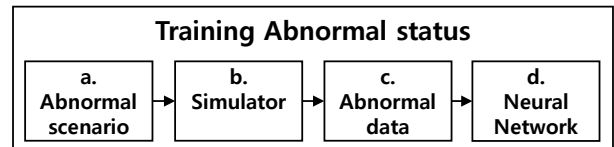

Fig. 3 Training configuration for abnormal status diagnosis

Even the abnormal status diagnosis system is developed with simulation data, the system should be tested and used with real plant data. For the test, normal operation and abnormal operation data should be used. However, the normal operation data has some differences compare to simulated normal operation data. Followings are main differences and counter measure for the differences.

a. Operation range bias

Many of variables have a certain band for normal operation. For examples water level of pressurizer has operation limit and alarm set-point for normal operation. In these cases, the simulated data and plant data the value itself have some bias in stabled operation condition. However the dynamics for abnormal status is similar. Therefore, when the normal operation data have some operation range bias, the changes of the plant data can be used for training.

b.   Normalization range

The training data should be normalized between 0 and 1 for neural network. To classify the status, the normalization range should be selected effectively. The normalization range may include normal operational range and abnormal event range. If some variable changes 5% from the average value during normal operational and changes 50% from the average during abnormal operation, the changes caused by abnormal event can be detected easily. If the value has its own fluctuation and is not changed during abnormal event, then the normalization range should be selected to ignore normal operating fluctuation.

c.   Low level fluctuation.

Some variable may have extremely large fluctuation. For example radiation level has changes a lot during operation. The effects of these changes should not affect the classification of abnormal status.

3. Test with plant data

When the training is completed, developed neural network is tested with normal and abnormal operation data from simulator and plant. Simulator data is used to test coverage aspect and plant data is used to validate the test result.
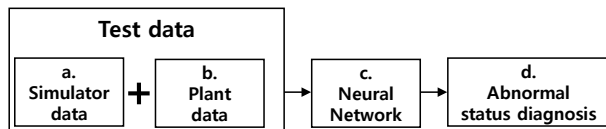

Fig. 4. Testing configuration for test

4. Convolution method and test result

Convolutional neural networks (CNN) have been widely and successfully applied for image classification [3-7]. To abnormal status diagnosis, the operational data should be used as input to the CNN. The strength of CNN is based on its convolution. The convolution is the process of data with adjacent data. Therefore the order of data should be selected with consideration of convolution effect. Also the abnormal data is time based data. Recently the convolution of data with time line has been researched. Input data to the CNN can be one set of operation data(snap shot data) at a certain time or series of data of operation data(time series data). Snap shot data has good representation of plant status but it is hard to reflect the changes of operational data according to time. Fig. 5 show the snap shot data for normal operation and abnormal operation. The snap shot data has been normalized and converted to gray scale for display. One set of snap shot data consist of about 2,000 data point. In

Fig. 5, "a" is snap shot data for normal operation and "b" is data for abnormal which is POSRV leak. "a" and "b" is slightly different in some data which is temperature affected by POSRV leak.
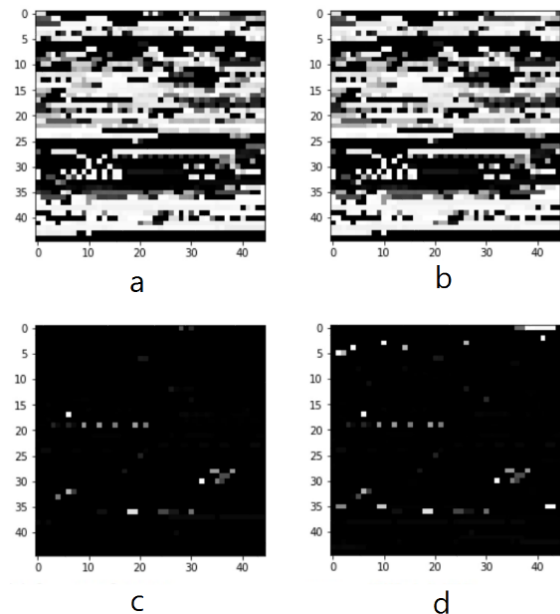

Fig. 5 Snap shot data for CNN input

"c" is snap shot data which is subtraction "a" from normal reference operation data and "d" is snap shot data which is subtraction "b" from normal reference operation data. Now we can easily distinguish "c" and "d". Fig. 6 shows the accuracy of neural network according to the mapping. Component based mapping for CNN has efficient accuracy compare to others. This result explains that the CNN recognize plant variable more accurate when the changed values are located in series.
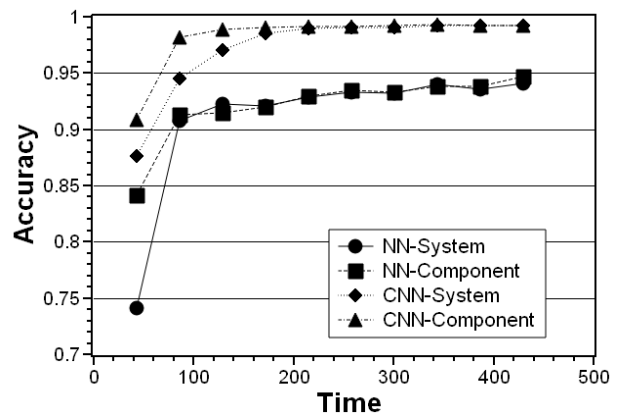

Fig. 6 Accuracy of modeling according to the mappings

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.

To diagnosis abnormal data the neural network is to be trained with snap shot data or time series data. The snap shot data still has enough information to classify the type of abnormal status with limited cases of input type. However, when the cases are increased, time series data have much data for diagnosis. To apply time series data convolution method between time lines should be developed.

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