Application of the PEANO to Kori NPP Unit 3 : Case Study

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1. Introduction

PEANO (Process Evaluation and Analysis by Neural Operators) is a system for signal validation and on-line calibration monitoring developed at the Institutt for energiteknikk (IFE), Norway. The empirical model applied in PEANO is based on Artificial Intelligence Techniques, such as Auto-Associative Neural Networks and Fuzzy Logic [1].

In this paper we applied Kori Nuclear Power Plant (NPP) unit 3 startup data to the PEANO and analyzed the results.

The rest of the paper is structured as follows, the technologies used in PEANO is described in Section 2. In Section 3 application results are described. Finally, in Section 4, the conclusions of the paper are presented.

2. PEANO modeling

In this section we describe the technologies used in PEANO. They are clustering, AANN, Robust training and recall process etc.

Clustering : The step-by-step procedure used to develop the fuzzy and possibilistic classifiers can be summarised as the following three-step process starting with the classic ISODATA algorithm.

- ISODATA : given a set of samples *X*, compute an initial set of cluster centroids using the ISODATA algorithm [2], which has been chosen because it automatically optimizes the number of required clusters.
- Fuzzy C-Means : initialise the elements of the partition matrix *U* with crisp values (0 or 1), using ISODATA. Then run the Gustafson-Kessel algorithm [3], which produces the fuzzy classifier.
- Pssobilistic Fuzzy Clustering : Use the updated centroids and membership functions, respectively to arrive to a possibilistic partition [4].

Neural Network Training : For each of the identified clusters an AANN will be developed. The AANN consists of an input layer, 3 hidden layers (2 mapping layers [H_1 and H_3] and a bottle-neck layer [H_2]) and an output layer. The mapping layers are usually of the same size, i.e. they have to same number of neurons.

The activation functions used in the processing elements are the hyperbolic tangent function in the input layer and the three hidden layers, whereas a linear activation function is used in the output layer.

Robust training : In order to increase the robustness against noise the simulated data are artificially corrupted by noise and small-scaled failures (spikes, steps, jumps etc.) Experiments confirm that networks trained by such signals are performing better with real data input. The PEANO algorithm and system give the user to option to control the number and size of the artificial failures that will be included in the input, as well as the noise level that will be added. The parameters that can be set are Noise level (%), Fault level (%) and Fault frequency (%).

The recall process : The recall process is the process where a new sample with measured values is taken and put through the neural network to obtain the estimate values for the signals. The recall strategy is as following :

- for each process sample: get the most representative cluster, which is the one with the highest membership grade *u1* in *U*
- recall the output using the neural network associated to this cluster
- calculate the maximum absolute deviation, as follows:

$$err1 = \max\left|s_j - o_j\right| \times \mathrm{sgn}\left(s_j - o_j\right) j = 1,..,N \qquad (1)$$

where s_j and o_j are the *j*-th input and output values of the network for a process pattern

- if *err*1 is very low, accept the result, otherwise recall the pattern using also the network with the second highest grade of membership, *u2*
- calculate the following weighted error:

$$werr = \frac{err1 \times u1 + err2 \times u2}{u1 + u2} \qquad (2)$$

where *err*2 is the maximum error with the second network. Now if:

$$abs(werr) > abs(err1) \qquad (2)$$

accept the output from the first network, otherwise calculate a weighted output from:

$$wout = \frac{out1 \times u1 + out2 \times u2}{u1 + u2} \qquad (3)$$

where *out*1 and *out*2 are the vector outputs from the two networks.

- if the difference in membership value *u1* and *u3* is not too large, repeat the above step for the calulation of *werr* and *wout* using also the network with the third highest grade of membership, *u3*.

3. Application Results

The real plant startup data of the Kori Nuclear Power Plant Unit 3 were applied to the PEANO. The data is derived from the following 11 types of measured signals: the reactor power (the ex-core neutron detector signal), the pressurizer water level, the SG steam flow rate, the SG narrow range level, the SG pressure, the SG wide-range level, the SG main feedwater flow rate, the turbine power, the charging flow rate, residual heat removal flow rate and the reactor head coolant temperature. The training and test data were taken from the original data and both data sets have 458 patterns sampled every 5 minutes.

The test data subset is divided into 2 clusters by the PEANO. There are 193 patterns in cluster #1 and 302 in cluster #2. Note that one pattern can be included in two clusters. We found that the optimum number of neurons in each layer are 7, 4, 7 for AANN #1 and 6, 4, 6 for AANN #2 by trial and error. Fig.1 shows normalized 11 input signals.

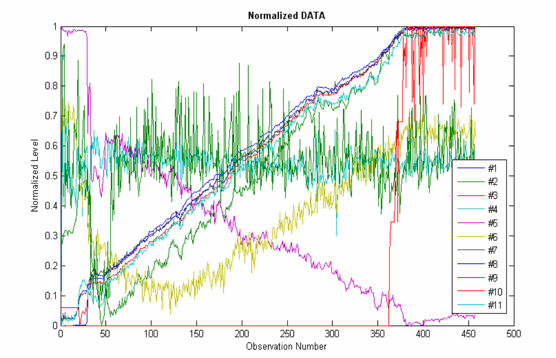

Fig. 1. Normalized input signals

Fig. 2 represents standard deviation and average deviation of residuals. From the figure we can know that the SG steam flow rate (Sensor 3) and the SG main feedwater flow rate (Sensor 7) have the highest standard deviation and average deviation in residuals, respectively.

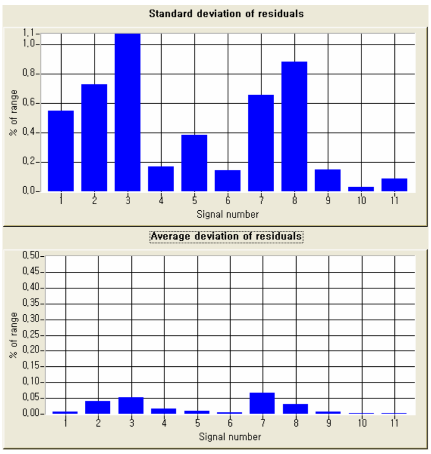

Fig. 2. Estimation results

In order to investigate the system's drift detection ability, we artificially induced in the SG main feed water flow rate channel (unit : Mkg/hr). The amount of drift is linearly increasing with time and its total amount of drift at the end point is assumed 5%.

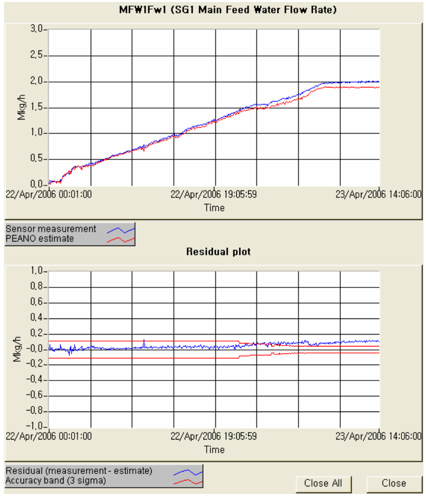

Fig. 3. Drifted signal and residual of estimate

Drifted signal and its estimate are depicted at the top in Fig. 6 while the residual at the bottom. We can use the accuracy band or Alarm threshold for the validation mismatch. The range of accuracy band with red lines in Fig. 3 is defined in multiples of the standard deviation and default value is 3σ. Alarm threshold can be defined as % of the sensor range. We can see that the residual is getting bigger and finally deviate from the accuracy band.

4. Conclusion

We applied Kori Nuclear Power Plant unit 3 startup data to the PEANO which developed at IFE and analyzed the results. It is very tolerant to noise because trained with noise and faulty signals. It should be noted that the PEANO needs an expert to train the AANN because the number of neurons in each layers are to be determined by trial and error.

REFERENCES

[1] Paolo F. Fantoni, S. Figedy, A. Racz, "PEANO, A Toolbox for Real-Time Process Signal Validation and Estimation" IFE, HWR-515, 1998

[2] Tou, R.C. Gonzalez, "*Pattern Recognition Principles*", p. 97,Addison-Wesley Publishing Comp., Reading, Massachusetts (1974)

[3] Gustafson, W.C. Kessel, *"Fuzzy clustering with a fuzzy covariance matrix"*, Proceedings of IEEE CDC, San Diego, Calif., Jan 10-12, 1979

[4] Krishnapuram, J. Keller, "A possibilistic approach to clustering", *IEEE Transactions on Fuzzy Systems*, Vol. 1, No. 2, 1993