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Actuator Fault Detection Using Adaptive Neuro Fuzzy Approach for Damadics Benchmark.

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ABSTRACT

Fault diagnosis systems are employed in many industries to increase safety andindicate the fault present in the systems .The objective of this work to develop a novel approach for fault diagnosis system using neural networks. Model based technique is proposed for detecting faults and diagnosis. The actuator model is designed using neural network and the best structure is chosen based on performance. Then the identified faults are classified using Adaptive neurofuzzy inference systems(ANFIS) classifiers. This approach is explained with actuator benchmark (DAMADICS).
Keywords: Neural networks, DAMADICS, ANFIS, Fault diagnosis

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INTRODUCTION

Control systems are implemented everywhere in the industry**.** Monitoring the chemicalprocessis mainly based on monitoring the current state of the system and indicate abnormal behavior of the system, and take preventive measures from accidents. The deviations from normal process behavior result from faults and errors. If faults could timely be detected and diagnosed in many cases it is possible to concurrently reconfigure the control system so that it can safely continue its operation [1].

Fault diagnosis is performed using these three categories model based method, model free method, process history based. In model based FDI parameter estimation, state estimation, observer design and soft computing technique are the most widely techniques. Most of the research works in FDI focused on the development of models, the models accurately approximate the nonlinear behavior of the system, to be used for generating residuals. Many techniques were developed based Fuzzy systems, Neural networks (NN), and Neuro Fuzzy Networks (NFN) [4].The faults can then be isolated by classifiers from statistics, fuzzy logic, NN, and NFN [10]. Since the Actuator system is highly nonlinear and many parameters are involved in this valve mathematical modeling. It is difficult to find the accurate model for control valve. To avoid like this kind of problem Artificial Neural Network (ANN) based system identification procedure is developed [13]. Artificial neural networks are widely used for developing the data based model.The residual generation via neural network is implemented by comparing the output of the fault free model with faulty model. Fault diagnosis can be done using some of the information's like location and time. The diagnosis task is comprises of fault detection, fault diagnosis, and decision making. This paper focuses on the generation of residuals using neural networks diagnose the faults using ANFIS (artificial neuro fuzzy inference system). This scheme is designed and evaluated to the benchmark DAMADICS (Development and Application of Methods for Actuator Diagnosis in Industrial Control Systems).

MODEL BASED FAULT DIAGNOSIS SYSTEM

The model based fault diagnosis can be defined as the identification of the faults present in a system by evaluating system measurements with the system's model developed by various techniques, the modeling error between the system and the developed model is obtained. Based on this residue value the fault is detected. The general block diagram for model based FDI is shown in Fig. 1. Fault detection can be done by setting thresholds. The basic idea in fault detection system is consists of two stages to produce signals that will indicate the residual between the normal operating condition and faulty operating conditions. That kind of signals are known as residuals are usually generated using a various kinds of methods [5]. Another stage is making the decision

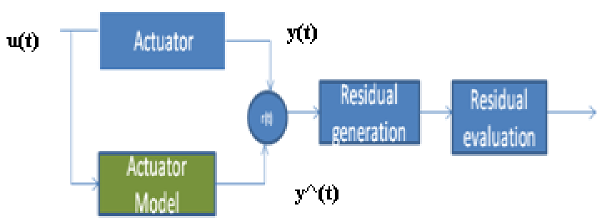

Figure 1: General Block diagram of Model based FDI

NEURAL NETWORK MODEL

The objective is to develop model that will be used for the residual generation[7],[14]. ANNs are used to develop the data driven models. ANN is trained with data collected during the normal operation and then the ANN models are validated with another set of data. The model is developed using various types of neural network and best network are chosen based on the performance indices.

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CASE STUDY (DAMADICS Actuator)

This procedure is studied for DAMADICS actuator which is the benchmark system mainly developed to analyze the various kinds of fault detection and isolation schemes. In Poland the Lublin sugar factory actuator is used as benchmark for DAMADICS [2]. The basic components of actuator are control valve, pneumatic servomotor, and positioner shown in Fig.2. The input to the Actuator is as follows process signal CV, inlet pressure P1and outlet pressure P2, liquid temperatureT1,The output of the Actuator is liquid flow rate F, and stem displacement X. The data set is collected from the DAMADICS website during various operating conditions which means with fault and fault free operating conditions [12]. The Actuator consists of 4 inputs and 2 outputs. The neural network model can be represented as MISO (multi input single output) for pneumatic actuator.
The modeling equation of valve using neural network shown below

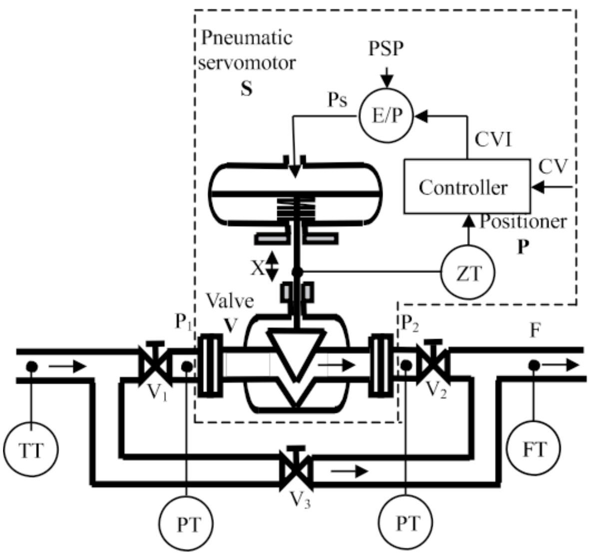

Figure 2: Actuator structure

V1 - hand driven bypass valve; V2 - hand driven bypass valve; V3 - hand driven bypass valve
P1 - Pressure sensor (valve inlet); P2 - pressure sensor (valve outlet); F - Process media flow meter
X - valve displacement

X'=net X (CV, P1, P2, T), (1)
F'=net F(X, P1, P2, T). (2)

The model is designed with tansig transfer function for hidden layer and purelin for output layer. The network is trained with data collected during normal operation and evaluated with another set of data. So this model will behave like the system (actuator).In the proposed system, nineteen type of faults are modeled by a bank of neural networks. The neural network modeling is shown in Fig. 3, Fig. 4. The data to train the network is collected from the DAMADICS website. Now the model will behave like a actuator system.

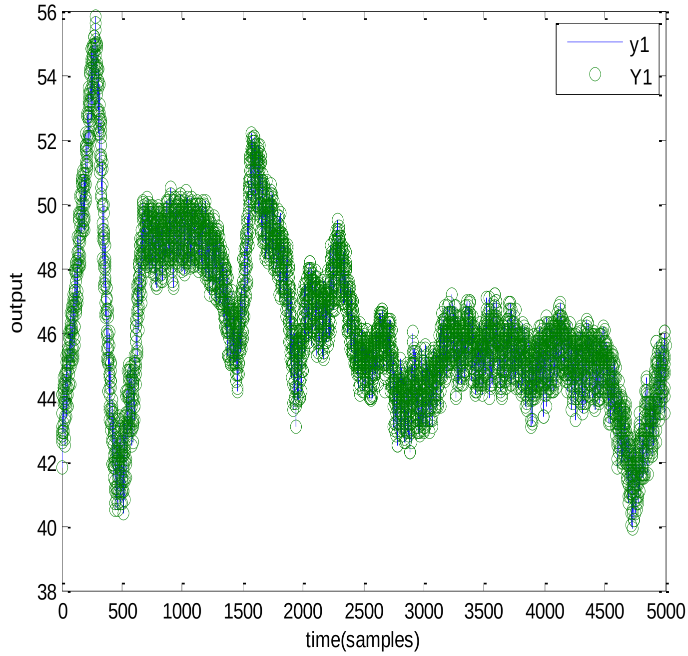

Figure 3: System and model output

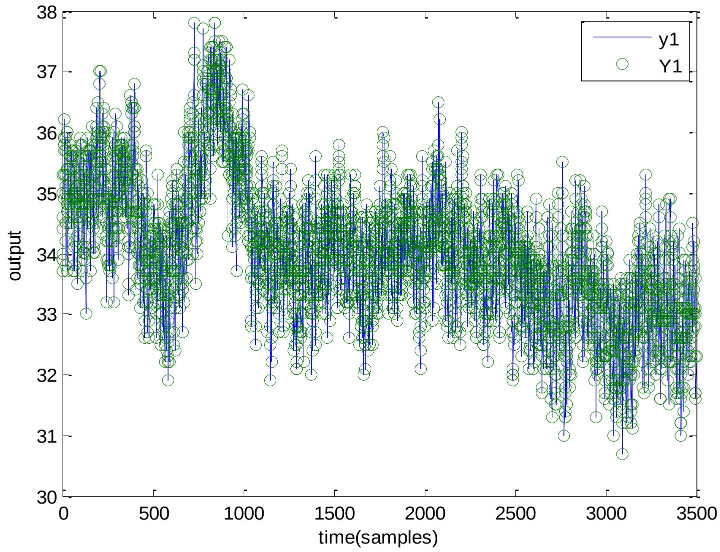

Figure 4: System and model output

FAULT DETECTION

The residual generation can be done by comparing the neural network output (fault free) with actual system measurement. In order to get the information about faults, simple threshold technique is used. If the residual values are smaller than the threshold value (0.3), a process is considered to be healthy, otherwise it is faulty. The detailed description of the fault types is shown in Table 1.

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Table 1: Faults to be detected and isolated

Fault	Description
	Control Valve Faults
f1	Valve clogging
f2	Valve or valve seat sedimentation
f3	Valve or valve seat erosion
f4	Bushing friction
f5	External leakage
f6	Internal leakage (valve tightness)
f7	Medium cavity or critical flow
	Pneumatic servo-motor faults
f8	Twisted servo-motor's rod
f9	Terminals tightness
f10	Servo-motor's diaphragm perforation
f11	Servo-motor's spring fault
	Positioner faults
f12	Electro-pneumatic transducer
f13	Rod displacement sensor fault
f14	Pressure sensor fault
f15	Positioner spring fault
f16	Positioner lever fault
f17	Positioner supply pressure drop
f18	Unexpected change of pressure difference
f19	Fully or partly opened bypass valves

It is not possible to segregate the type of fault based on magnitude because some faults are having same -magnitude (f1, f7, f10) .So the one kind of solution is that faults are classified using soft computing techniques. The residual between the system and model output for the detected two faults is shown in Fig.5, Fig.6.

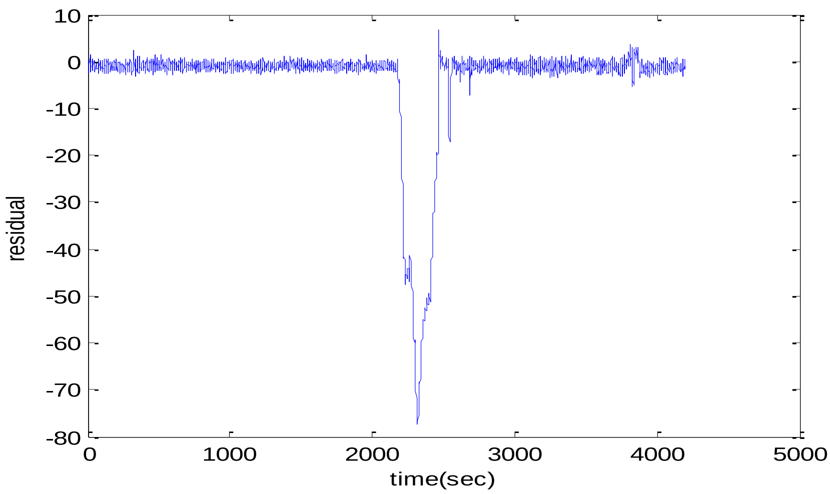

Figure 5: Residual between system and neural network output for f1

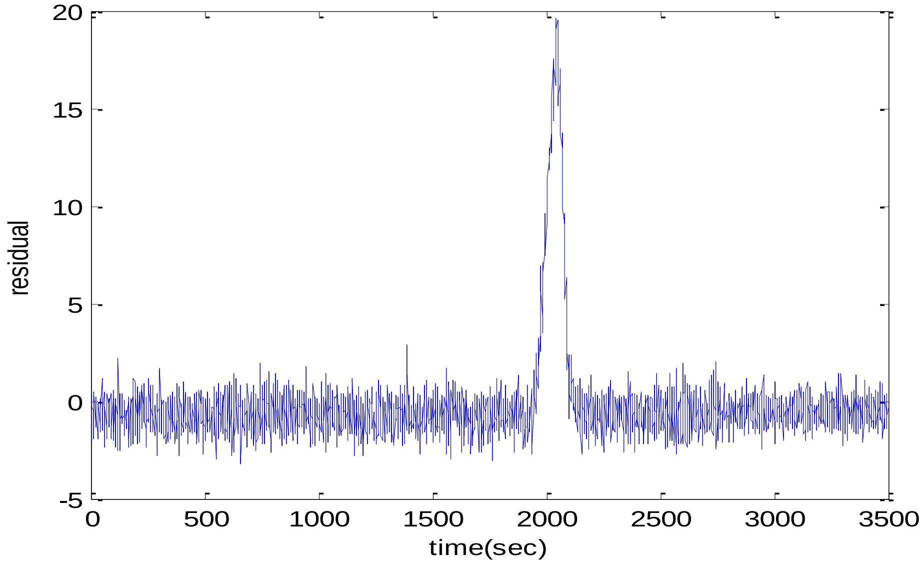

Figure 6: Residual between system and neural network output for f2

FAULT CLASSIFICATION

After generating the residuals of each fault; the next step is to classify the detected fault. We used neuro-fuzzy classifiers on training procedures. ANFIS use five layers for calculating the network output. The block diagram of ANFIS is shown below in Fig. 7.

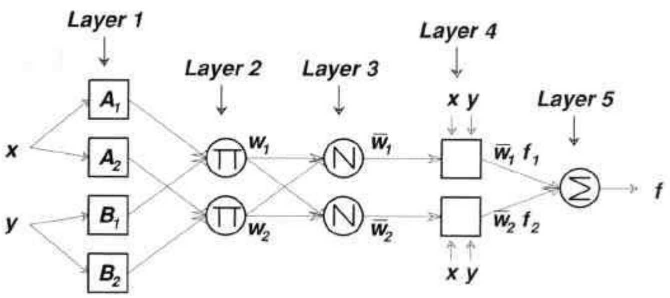

Figure 7: ANFIS general architecture

In the first hidden layer thefuzzification process is carried out, the second hidden layercalculates the degree of each rule. Normalization operation is carried out in the third hidden layerand the network output is calculated by the fourth layer.

FEATURE EXTRACTION

Many feature extraction techniques were projectedlike time domain, the frequency domain. Feature extraction method is used to trim down the dimension of the data. By doing this the relevant features can be extracted from the data. We have used some of the feature extraction methods like mean, variance, skewness, kurtosis, standard deviation, frequency, power spectrum, root mean square etc.

$$X\_skew = \frac{(\sum_{k=1}^{k}(x(k)-x)^3}{(k-1)s^3} \quad (3)$$

$$X\_kurtosis = \frac{\left(\sum_{k=1}^{k} x(k)\right)-x)^4}{(k-1)s^4} \quad (4)$$

max(measured variable)
Where

x - measured variable
z -standard deviation

The neuro-fuzzy classification system consists of three inputs and one output. The inputs are the features and the outputs are faults (f1,f2). ANFIS which is trained of 9 rules. The triangular membership function is used. The error is approximately 0.3307.The f1 appears between 40-60 sec, and f2 is appears between 80-90 sec.

CONCLUSION

In this paper, neural network based model is presented for intelligent fault diagnosis. The proposed -diagnosis system is used for detecting two faults in DAMADICS actuator and the result is shown in Fig. 8. ANFIS system is well suited for designing intelligent systems because it is capable of making inference with a learning capacity of neural networks. The simulation results and Table 2.Show the efficiency of the proposed scheme for fault diagnosis. The drawback of this model based FDI is we can implement this technique onlyfor known working condition. The unknown faults can be detected but the faults cannot be isolated using the magnitude and multiple fault detection is very difficult. Future work will think about the expansion of the developed FDI technique to N number of fault detection.

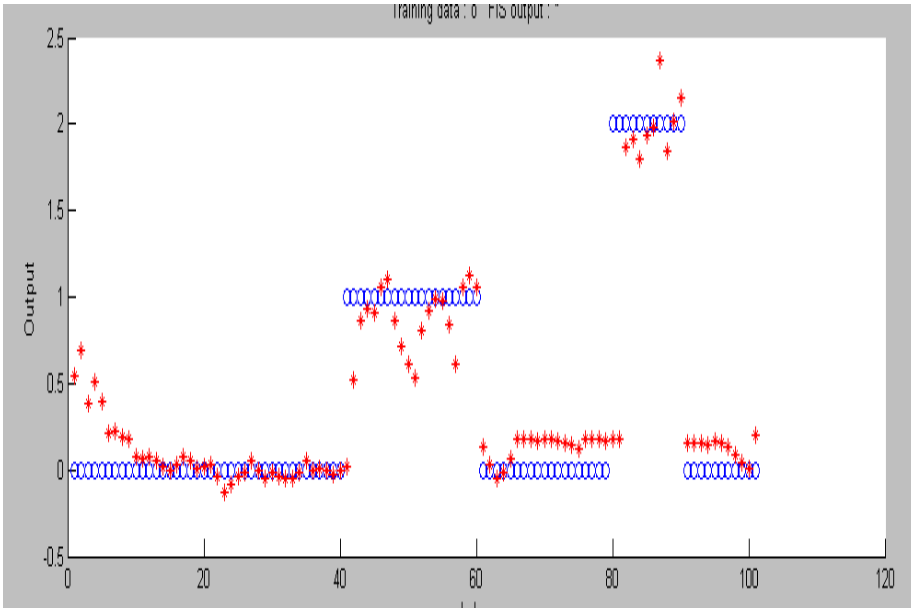

Fig 8: ANFIS classification for detected fault

Table 2: Testing data for ANFIS classifier

Input parameters	Output (type of fault)
0.0039,-0.970	1
0.5089,-0.851	2

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