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Control of Neutralization Process Using Soft Computing

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Abstract: A novel model-based nonlinear control strategy is proposed using an experimental pH neutralization process. The control strategy involves a non linear neural network (NN) model, in the context of internal model control (IMC). When integrated into the internal model control scheme, the resulting controller is shown to have favorable practical implications as well as superior performance. The designed model based online IMC controller was implemented to a laboratory scaled pH process in real time using dSPACE 1104 interface card. The responses of pH and acid flow rate shows good tracking for both the set point and load chances over the entire nonlinear region. *Copyright © 2008 IFSA.*

Keywords: Nonlinear, Neutralization process, IMC and NN

1. Introduction

The main objective of pH processes is to control the pH value by manipulating the flow rate of acid titrating stream. The control of pH is important in the chemical industry, especially in wastewater treatment. However, pH processes are difficult to control due to their nonlinear dynamics with uncertainties. For this reason, pH control by conventional PID controllers [1] or advanced control techniques based on linear system theory is ineffective. McAvoy et al. [2] have explained the dynamic physico-chemical behavior of pH in continuously stirred tank reactors. They have derived the dynamic equations for the acetic acid sodium hydroxide neutralization process and have compared them with experimental results. To operate over the entire region of the highly nonlinear pH process, controller has to adapt for the changes in the process parameters [3]. To achieve this, generally model based controller design techniques have been proposed to deal explicitly with process nonlinearities [4]. The key issue in most of the approaches that rely on input/output models has been a process model structure with critical properties. In this realm, many literature has appeared on the use of NN models for nonlinear process control [5,6].Generally, NNs have been trained to model either the process behavior or its inverse and subsequently used in model based control schemes including adaptive control, feed forward control, model predictive control (MPC), and internal model control (IMC). The extension of the linear internal model control (IMC) strategy to nonlinear systems has been a popular model-based control approach [7, 8].Several nonlinear IMC schemes for NN models have recently been proposed [9] for chemical process applications. In this work, an adaptive IMC design strategy is proposed to control the pH neutralization process using NN structure.

2. Experimental Set Up

A weak acid-strong base system is chosen for control. Acetic acid and sodium hydroxide are taken as reagents for the process, the reaction is

$$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O \quad (1)$$

The experimental setup is shown in Fig. 1.The continuously stirred tank reactor is one of the widely adopted mixing tank in industries and hence taken up as the mixing vessel. It has two input streams, one containing sodium hydroxide (NaOH) and the other acetic acid (CH_3COOH). Acid and base are stored in acid and base tank respectively. Perfect mixing is provided using stirrer to maintain uniform concentration through out the reactor. In this work, base flow rate is kept constant (0.3 L/min) and only the acid flow rate is varying (0 to 0.5 L/min). The experimental description of the pH control system is as following. The vessel is made of stainless steel of capacity 7.4 liters. The vessel is provided with two nozzles, used to feed the inlet streams (acid and base) into the tank. The contents of the tank are agitated well by a four-paddle stirrer, driven by a variable speed motor. The vessel is also provided with a drain pipe at the bottom to drain the liquid from the tank at the end of every experiment. The dozer valveless metering pumps (M/s Fluid Metering Inc.) pumps the acid and base streams into the mixing tank. These pumps can be actuated either manually or by a current signal 4-20 mA. By varying the current signal the flow rate can be linearly varied. The pH of the solution is measured on-line by a glass type pH electrode. Two separate reservoir tanks are used to feed acid and base solutions to the reactor. The inlets to the metering pumps are connected to the nozzles outlets located at the bottom of the reservoirs. The outlets of the metering pumps are connected to the feed inlet nozzles of the mixing vessel. The process pumps and sensor are interfaced with computer using dSPACE 1104 real time data acquisition card. The card can be connected directly to the PCI slot through parallel port of the computer. It has an inbuilt Power PC microprocessor, Slave Digital Signal Processor (DSP) processor with 32 MB SDRAM and 8 MB flash memory. The card supports 8 ADC and 8 DAC channels with voltage range of ± 10 V. The conversion speed of the card is 2 μs for ADC with 16-bit resolution and 10 μs conversion speeds for DAC with 16-bit resolution. The program developed in MATLAB software is converted into C-code and dumped into the dSPACE card. The real time monitoring, acquisition and action are performed using modules built in Control Desk software provided with the data acquisition card. Programs are written so that the data acquisition and control action calculations could be completed within this sampling time. The experimental parameters are shown in Table 1.

Fig. 1. Real time experimental pH process setup.

Table 1. Experimental parameters.

Variable	Meaning	Initial setting
V	Volume of the tank	7.4 L
F_A	Flow rate of acetic acid	0 -0.5 L/min
F_B	Flow rate of NaOH	0.3 L/min
C_A	Concentration of acetic acid	0.2 mol/L
C_B	Concentration of NaOH	0.1 mol/L
K_A	Acid Equilibrium constant	1.8×10^{-5}
K_w	Water Equilibrium constant	1.0×10^{-14}

For the 0.5 L/Min acetic acid flow rate step change with the constant disturbance of 0.3 L/min NaOH flow rate, the obtained titration curve is shown in the Fig. 2.

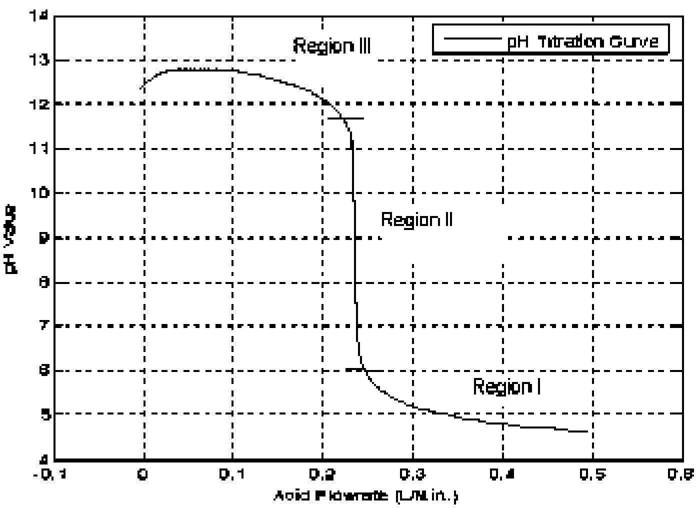

Fig. 2. Experimental open loop titration curve.

3. Adapting IMC Structure using NN

The need for NNs arises when dealing with non-linear systems for which the linear controllers and models do not satisfy the use of structures provided by classical control theory. Some of structures adopted from classical control can be used directly with NN models, but IMC needs some refinements to work properly. The good match between forward and inverse models, referred from Fig. 3. translates to having the forward model outputs feedback to the input of the inverse and direct model instead of the outputs of the plant. This means that the inverse model will implement the following equation:

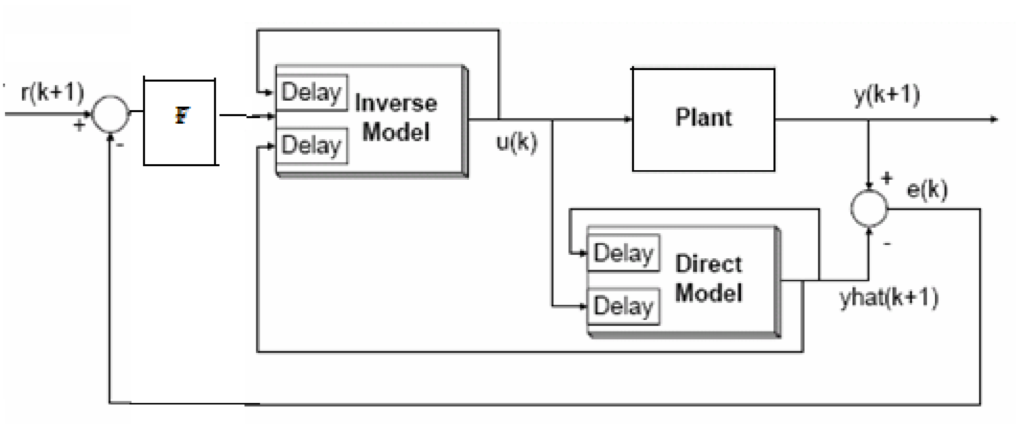

Fig. 3. Adapting Internal Model control structure.

$$u(k) = g\begin{bmatrix} r(k+1), yhat(k),....., yhat(k-n_y+1) \\ u(k-t_d),....u(k-n_u-t_d+1) \end{bmatrix} \tag{2}$$

Instead of,

$$u(k) = g\begin{bmatrix} r(k+1), y(k),....., y(k-n_y+1) \\ u(k-t_d),....u(k-n_u-t_d+1) \end{bmatrix}, \tag{3}$$

where n_y is the number of previous output samples used, n_u is number of previous control signal samples used and t_d is the time delay of the system.

4. NN Based Modeling

The control input sequence for the training of the internal model consist of pulses of random amplitude in the range [0; 0.5] with a different duration of sampling periods is shown in Fig. 4. for a total length of the 1000 sequence. In this modeling multilayer perceptron NN structure is used and Levenberg-Marquardt algorithm is used as learning algorithms. Tan sigmoid function is hidden layer activation functions and log sigmoid functions are the output layer function. Filter is introduced here in between error output and controller input. This will make the loop reliable by reducing the controller order. Here for the pH process unit magnitude first order filter is selected. Time constant of filter is a tuning parameter to produce a better performance and for this particular process 10 sec is selected as a time constant. The corresponding training and Validations are shown in Figs. 5 and 6.

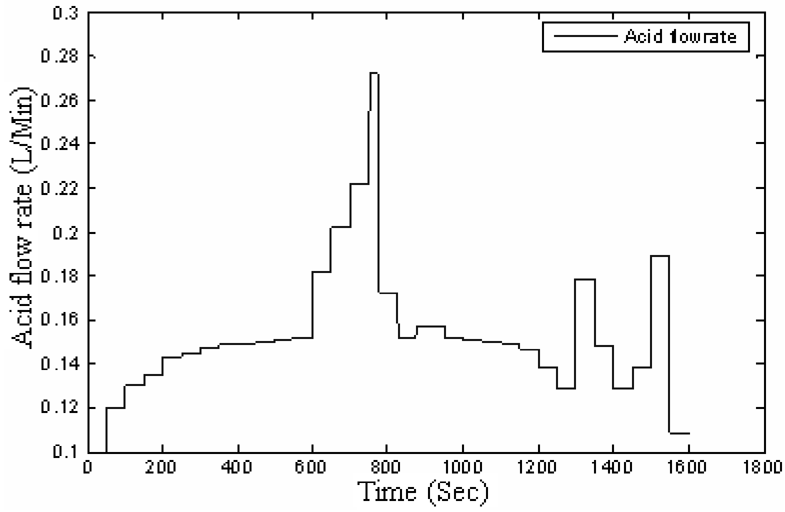

Fig. 4. Excitation signal for process model.

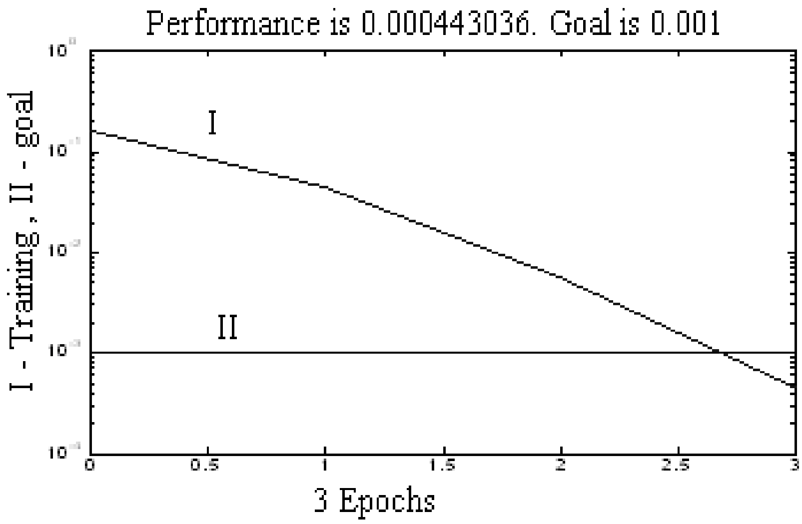

Fig. 5. Training.

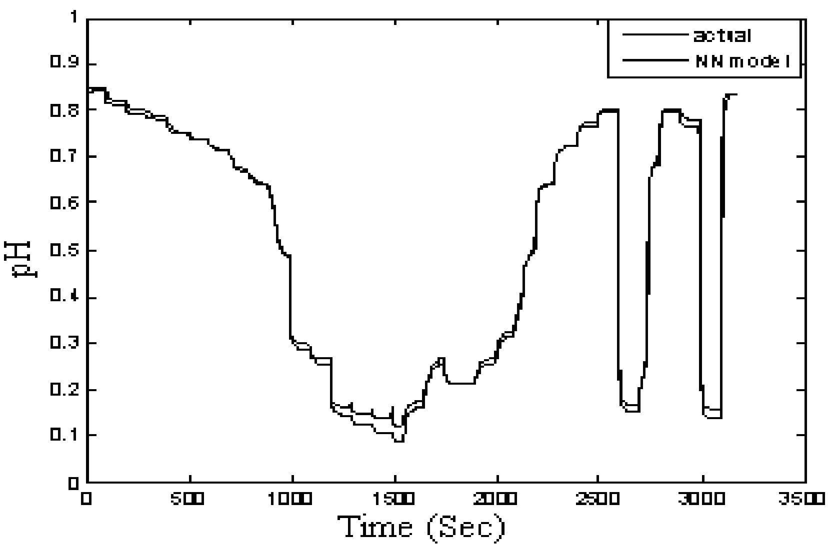

Fig.6. Validation.

Design of the Inverse Models

The process is to be controlled for set point pulses of amplitude in the range [0; 1] with a different duration of (10, 20, 30) sampling periods; the total length of the sequence is 1000. Multilayer perceptron NN structure is used and LM algorithm is used as learning algorithms. The process excitation signal is shown in Fig. 7. Tan Sigmoid functions are hidden layer activation functions and log sigmoid functions are the output layer function. The corresponding training and Validations are shown in Figs. 8 and 9.

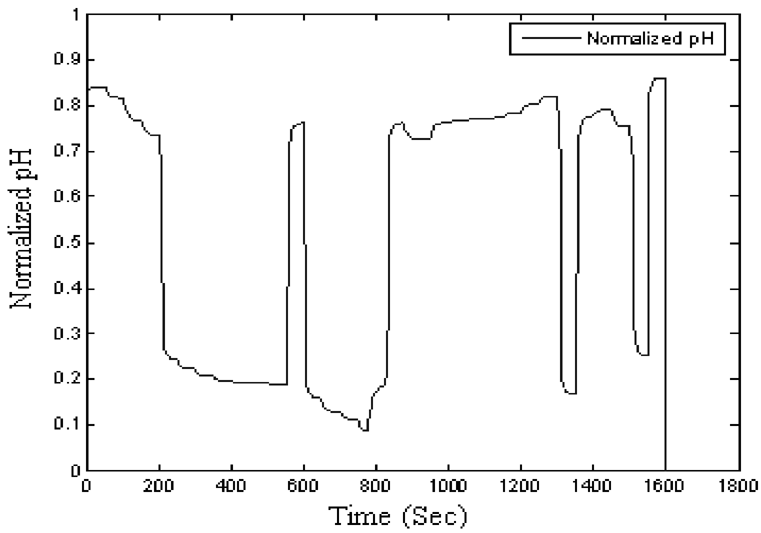

Fig. 7. Excitation signal for inverse of process.

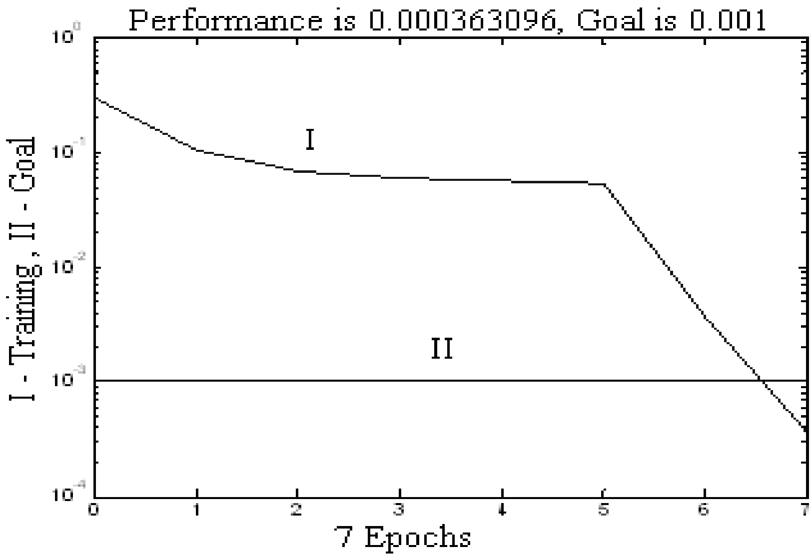

Fig. 8. Training performance of inverse of process.

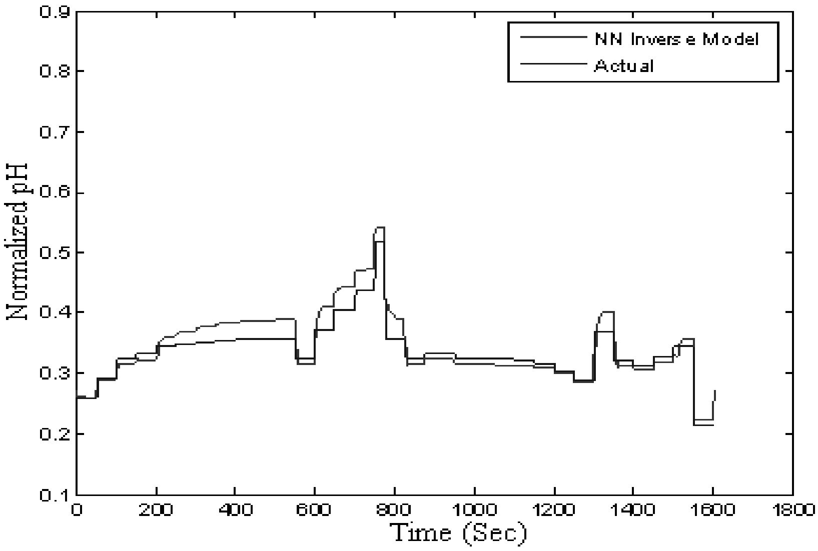

Fig. 9. Validation performance for inverse of process.

5. Results and Discussions

The process equations are used to develop a process model and a simple closed loop control strategy. Controlled variable and manipulated for the set point and load tracking of NN based IMC responses were shown in Fig. 10-13. It shows good response for both set point and load changes. Offset for the set point change was very small, fast response, its rise was comparatively less. For small filter time constant, produce a more oscillatory response due to its controller aggressive. But, for the large value of filter time constant shows sluggish response. The optimum selection of filter time constant can produce better response. Manipulated variable for both set point and load changes were also shows oscillatory.

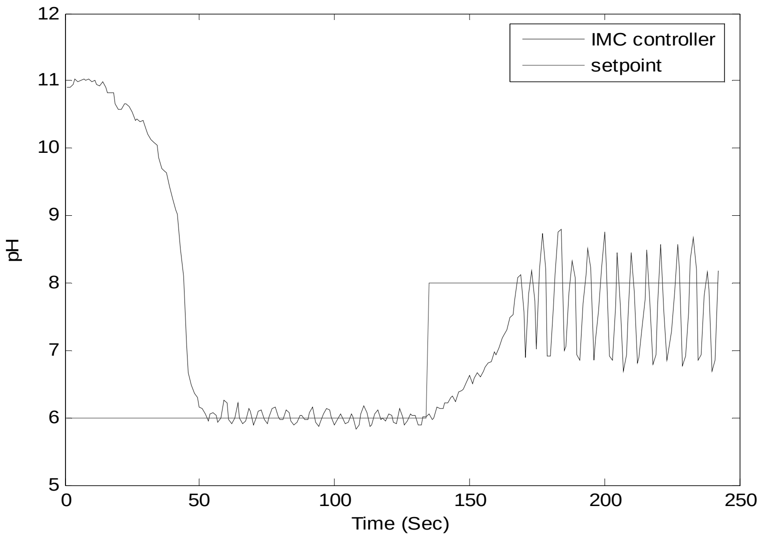

Fig. 10. Controlled variable for set point tracking of NN based IMC.

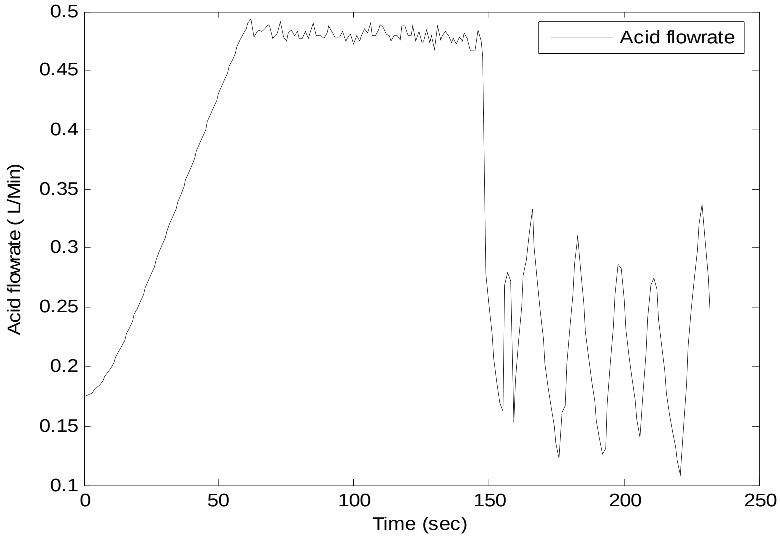

Fig. 11. Manipulated variable response of set point tracking of NN based IMC.

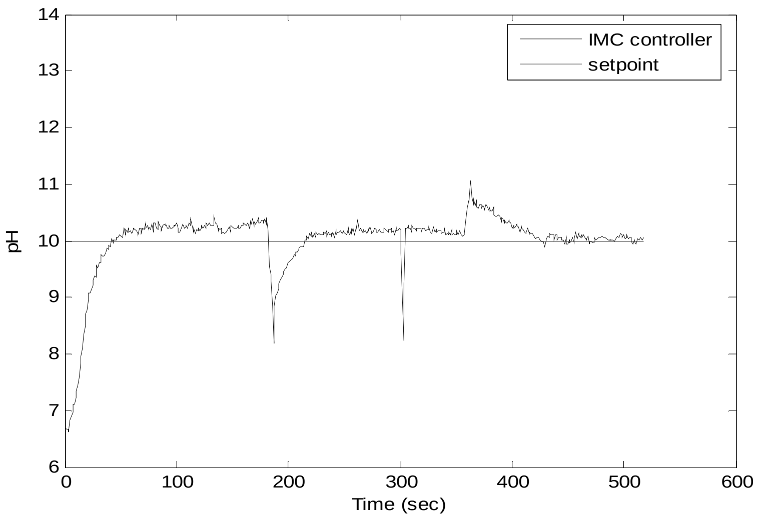

Fig. 12. Controlled variable for Load tracking of NN based IMC.

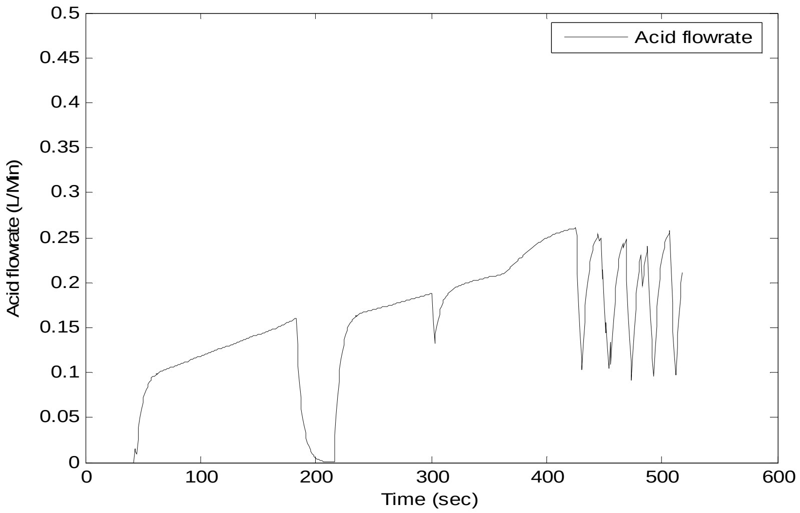

Fig. 13. Manipulated variable response of load tracking of NN based IMC.

Table 2. Performance analysis of Non liner IMC controller.

Step change (pH)	ISE	IAE	Overshoot percentage	Settling time
6 to 8	177.8	143.4	9.95	110

6. Conclusions

The experimental open loop titration curve for acetic acid and sodium hydroxide neutralization process shows nonlinearity in process parameters. An online NN based adaptive IMC technique based control strategy was developed. The mean square error cost function reduction based adaptation produces both set point and load tracking better. The designed NN based model based IMC controller was implemented in real time pH process. For the controller design Matlab-Simulink was used and for the interfacing dSPACE 1104 setup was used. The performances of the controller for the set point and load changes shows better tracking over the entire operating region.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
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- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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