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Artificial neural network control of a heat exchanger in a closed flow air circuit

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Abstract

This paper experimentally investigates the control of a heat exchanger in a closed flow air circuit. The temperature inside the test section of the test facility has been maintained at a set value by variation of air flow rate over the heat exchanger tube surface and the water flow inside the heat exchanger tubes. The neural network based control has been implemented in a Labview platform and compared with the PID control. The performance of the controller has been investigated for multiple changes in set points and under externally imposed disturbance. The neural network based control has higher speed of response and the steady-state error for the neural network control has a smaller average value than that of the PID control. The control action based on the neural network technique shows less oscillation in comparison to that of the PID based control. Dual actuations, i.e. both air flow and water flow control, have better performance than that with single actuation, i.e. either air flow or water flow control. Both the ANN and PID based control are equally robust in the presence of externally imposed disturbance.

Keywords: Neural network control; Heat exchanger; Multi-layer perceptron; PID control; Air circuit

1. Introduction

Many industrial applications use PID control to maintain constant process variable. The neural network based model is capable of accurately modeling non-linear complex dynamical systems. Thermal systems are inherently non-linear and complex in nature due to the importance of many phenomena such as leakage, friction, temperature-dependent flow properties, contact resistance and unknown fluid properties, etc. Thus, thermal systems are not easily amenable to mathematical modeling. Therefore, neural network based control is expected to be a better alternative to the PID control due to its capability in accurately modeling non-linear thermal system.

Many investigations have demonstrated the capability of neural network control. Psichogios and Ungar [1] evaluated the internal model control and multi-step predictive control of a non-linear exothermic continuously stirred tank reactor and observed excellent controller performance in set point tracking with minimal steady-state offset. Nahas et al. [2] proposed a non-linear internal model control strategy

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Nomenclature

K	process gain
K_c	proportional gain of controller
t_D	dead time
t_G	equalizing time
τ_I	integral time
τ_D	derivative time
e	error between set point and actual
t	time
x	input process value
y	output process value
w	weight between the nodes
m_w	water flow rate
m_a	air flow rate
T	temperature
λ	learning rate
δ	neural network model error
μ	momentum factor
l	iteration counter
b	bias
ϕ	activation function
J	number of nodes in a layer
o	target output

consisting of neural network model based inverse controller and demonstrated from the simulation results of a continuous stirred tank reactor and a pH neutralization process that the neural network based control strategy outperforms the conventional PID control. Curtiss et al. [3] compared the neural network based controller with PID controller for a HVAC application and observed minimal rms error for the ANN controller in comparison to the PID controller.

So et al. [4] reported the application of an artificial neural network for system identification and control of a commercial air handling system with multiple input and output. Excellent performance of the neural network identifier/controller was observed in comparison to the PID controller where the control actions have been carried out by minimizing two error terms in the performance index, i.e. the set point error and the total energy consumption. Bittanti and Piroddi [5] applied a neural network based control to the control problem of regulating the output temperature of a liquid-saturated steam heat exchanger and compared the effectiveness of the neural control schemes with classical linear controllers. They observed intense abrupt oscillations of the control action for the PID control in comparison to modest oscillation of the control action in case of the neural network control. The response speed of the neural network control was faster than the PID control. However, the robustness to disturbance was superior for the PID control in comparison to the neural network control.

Pacheco-Vega et al. [6] compared the neural network and conventional correlations for heat transfer predictions of the fin tube multi-row multi-column compact heat exchangers and observed the neural network to be more accurate than the conventional correlations. Pacheco-Vega et al. [7] proposed a cross-validation technique to find regions where not enough data are available to construct reliable neural network for heat rate estimations of heat exchangers used in refrigeration applications. Diaz et al. [8] applied an adaptive artificial neural network for a compact heat exchanger control based on minimization of target error, stabilization of the controller and minimization of energy consumption. They observed that the neural networks are useful for the control of thermal systems that may change over time. Panigrahi et al. [9] demonstrated the efficacy of neural network in modeling of turbulent statistics behind a square rib mounted in the free stream of a wind tunnel. Nanayakkara et al. [10] presented a novel neural network whose parameter adaptation was governed by evolutionary algorithm to avoid local minima convergence. They designed the neurons with a non-linear static part coupled with a linear dynamic synaptic part contrast to the conventional neural network where the neurons are non-linear static and the weights are scalar values. The new neural network approach reduces the complexity and time consumption for computing and faster convergence during the training process. Melin and Castillo [11] adopted a hybrid neuro-fuzzy-fractal method for control of complex aircraft dynamic systems, which was successful in combining the advantages of neural network (ability for identification and control) with the advantages of fuzzy logic (ability for decision and use of expert knowledge). The complexity of the process to be controlled was characterized by fractal dimension which was used to represent the possible dynamic behavior of the system. Panigrahi et al. [12] compared the fuzzy logic and the neural network for