Academic Science

International Journal of Electronics, Electrical and Computational System
IJEECS
ISSN 2348-117X
Volume 6, Issue 8
August 2017

ANFIS and Lyapunov based MRAC of Jacketed Stirred Tank Heater

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ABSTRACT

Paper discusses analysis of applying model reference adaptive control strategy for control of temperature in jacketed stirred tank heater. Perfectly mixed hot fluid is circulated in heater through the jacket. Modeling of jacketed stirred tank heateris done with energy balance equations on the vessel and on jacket fluids and same has been used for simulation. Initially Lyapunov rule technique has been applied for simulation of MRAC. Adaptive control parameter values of θ and output have been saved and used for future control strategy with soft computing. By applying adaptive neuro fuzzy inference system (ANFIS) based algorithm adaptive parameter values have again been generated. Results shows that as compared to conventional MRAC soft computing based MRAC leads to better result in several cases. Basics of Lyapunov rule based adaptive control, literature survey, dynamics of jacketed stirred tank heater and MRAC with result statistics have been presented.

KEYWORDS

JSTH, Lyapunov rule, MRAC, ANFIS

INTRODUCTION

Jacketed stirredtank heater (JSTH) is widely used in process, food and beverage industries. In various research laboratories JSTH setups are useful for experiments or to verify simulation exercises.Modeling of chemical processes, design and simulation of important process control strategies and dynamics for bench-mark systems have been discussed in [1]. Jacketed heater model has been used here to test and simulate model reference adaptive control (MRAC) strategy in present work. Second order dynamics of heater with jacket system has been discussed. Order of Plant and model is same for MRAC simulation purpose.Fig.1 presents Block diagram of ANFIS or Lyapunov based MRAC applied for present simulation work. At each instant difference of plant output and model output has been used to adapt controller. Fig.2 presents layer wise ANFIS structure for parameter adaptation.

Initially a gradient scheme MIT rule was represented as $\frac{d\theta}{dt} = -\gamma e \frac{\partial e}{\partial \theta}$ where $e = error = y - y_m$. MRAC can be applied as MIT rule, Lyapunov stability method and various modified strategies explained in [2].

NN based temperature control in jacketed stirred tank heater has been presented and results are presented for MIT rule and NN based MRAC in [3]. In [4] detailed discussion of advantages and disadvantages of steamand hot water for jacketed heating, and discussion of indirect and direct steam injection systems formaking hot water is given with nice conclusions.

For a non-linear stirred tank heater based on its mathematical equivalent model control architecture and controller design has been presented in [5] for one and two manipulated variables. MPC and PID based controller results are presented and compared to maintain the tank temperature at fix, steady state value. Simulation of continuous stirred tank heater (CSTH) experimental pilot plant are given in [6]. Volumetric equations, heat balance equations and algebraic equations have been derivedand equations are used for

calibration purpose. Nonlinearities and hard constraints are considered to present work.Measured values are used in place of simulated to make a realistic platform for purpose of system identification and fault detection.

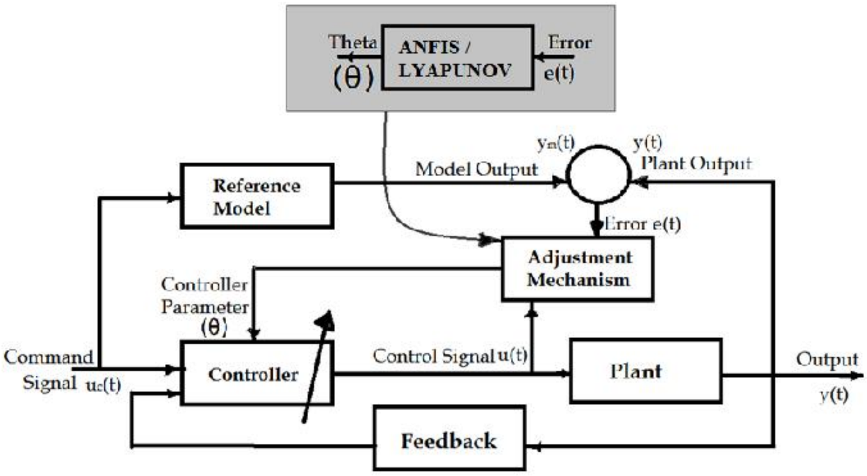

Fig 1: Block diagram of ANFIS/ Lyapunov based Model Reference Adaptive Control

Nonlinear model predictive control (NMPC) based on multiple neural networks is discussed in [7]. The control scheme includes a process model and an optimizer. Multiple neural networks helps to model the process and the model helps in an NMPC scheme to control the process. Improved generalization and noiserobustness capabilities are shown compared to a single neural network. Genetic algorithm based optimizer determines solution for the control trajectory which helps for real-time control of a CSTH. Neural Network -based MRAC has been suggested in [8].It consists of an online multilayer back propagation neural network structure along with a conventional MRAC.The training patterns for the NN are obtained from the conventional PI controller.

ANFIS based MRAC controller for speed control of DC servo motor, simulation results and stability of adaptation parameter are discussed in [9].Fuzzy based MRAC of a nonlinear system over a network subject to variable network induced time delay has been proposed in [10]. It is shown capable of controlling the system over a network subject to variable network-induced time delay with bounded tracking error. Parameter stability has been proven and effect of packet losses and control has been discussed.

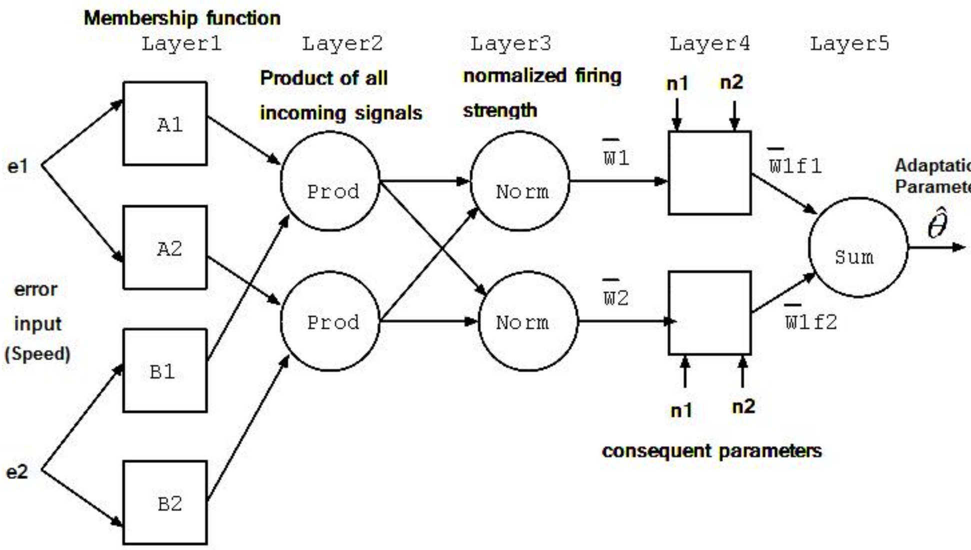

Fig 2: ANFIS Layer-wise Structure for Adaptation Parameter[9]

Due to benefit of NN and fuzzy logic both ANFIS proves better soft computing tool for adaptation mechanism. Next Section discusses dynamics of system under consideration followed by results and discussion of simulation. Finally work has been compiled.

Dynamics of Stirred Tank Heater with Jacket

A perfectly mixed hot fluid is circulated in the jacket of a jacketed stirredtank heater. Fig. 3 Showssketch of jacketed stirredtank heater. Heat flow between the jacket and vesselresults in more heat energy content of the vessel fluid. Heat transfer rate from the jacket fluid tothe vessel fluid is

$$Q = H_c A[T_j - T] \quad (1)$$

Where H_c is the overall heat transfer coefficient and A is the area for heat transfer. Volume and density are assumed to be constant, Feed rate *Fin=F*.

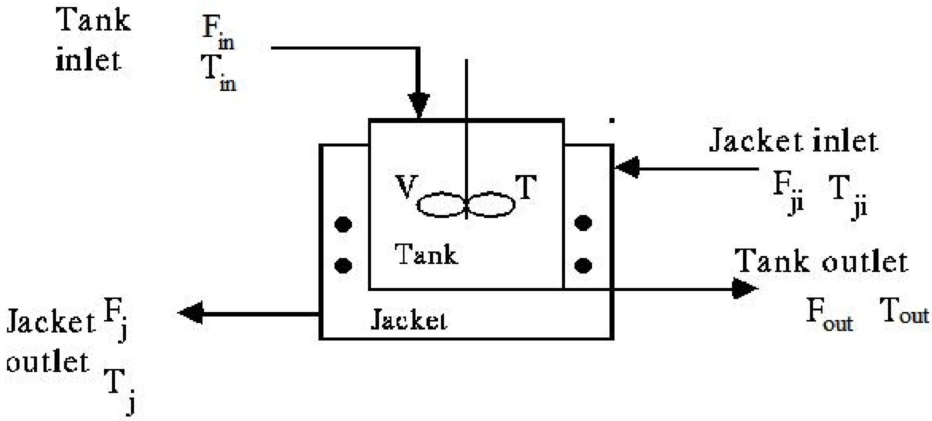

Fig 3: Diagram of Jacketed Stirred Tank Heater

Mass and Energy balance principle are used for modeling the system. Energy balances on the vessel and jacket fluidsgives following model equations.

$$\frac{dT}{dt} = \frac{F}{V}(T_{in} - T) + \frac{H_c A}{V \circ c_p}(T_j - T) \quad (2)$$

$$\frac{dT_j}{dt} = \frac{F_j}{V_j}(T_{ji} - T_j) - \frac{H_c A}{V_j \circ_j c_{pj}}(T_j - T) \quad (3)$$

Outputs vessel temperature and jacket temperatures can be considered as system states also. System inputsare the jacket flow rateF_j, feed flow rate$F$, feed temperatureT_{in}, and jacket inlet temperatureT_j. Desired set value or set trajectory should be maintained for vessel and jacket temperatures.

RESULTS & DISCUSSION

Simulation study has been carried out for Lyapunov based MRAC in first part. Values of error and adaptation parameter are saved and used for learning and training purpose in second part for ANFIS based MRAC.

Values of parameters for simulation are

F=0.02 with ±0.02 variation; V=1; F_j=0.1; V_j=1; HC=.05 with ±0.01 variation; A=1; V=1; r=1; c_p=1; v_j=1; r_j=1;c_{pj}=1; T_{in}=10; T_{jin}=1 and adaptation gain gamma γ=2.1.

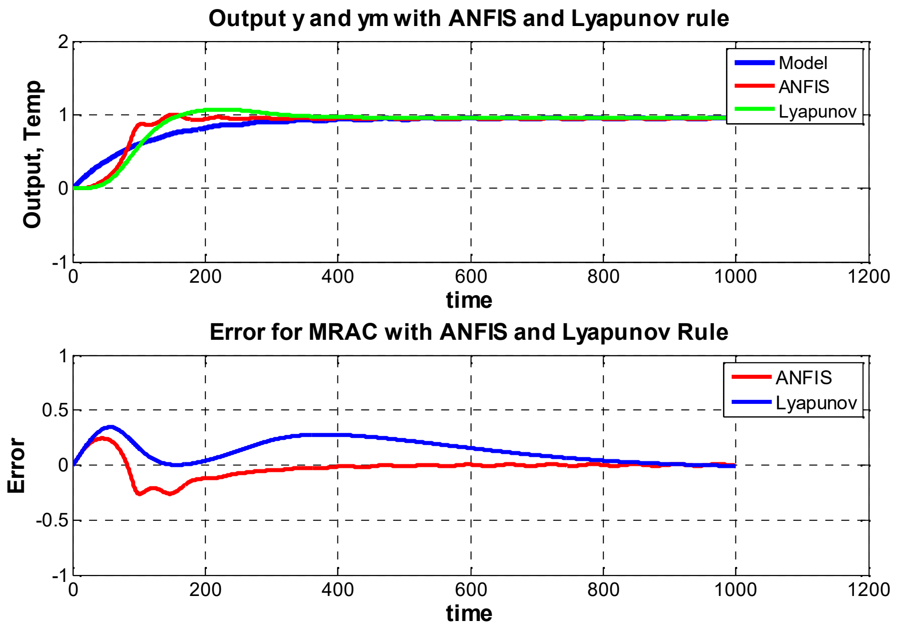

Fig 4: Output and Error with Lyapunov Rule and ANFIS based MRAC with Jacketed Stirred Tank Heater

Results in Fig. 4 shows strength and features of both applied adaptive control strategies. After initial oscillations error goes to zero in cases of ANFIS and Lyapunov based MRAC respectively.

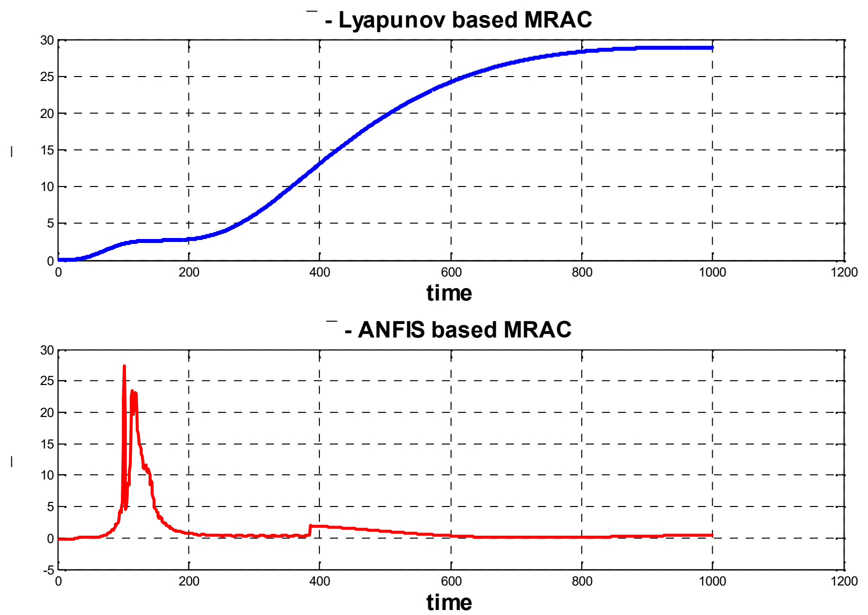

Fig 5: Adaptation Parameter for Lyapunov based and ANFIS based MRAC

Variation in adaptation parameter can be observed in Fig. 5. After initial variation ANFIS based strategy adapts with much less energy cost.

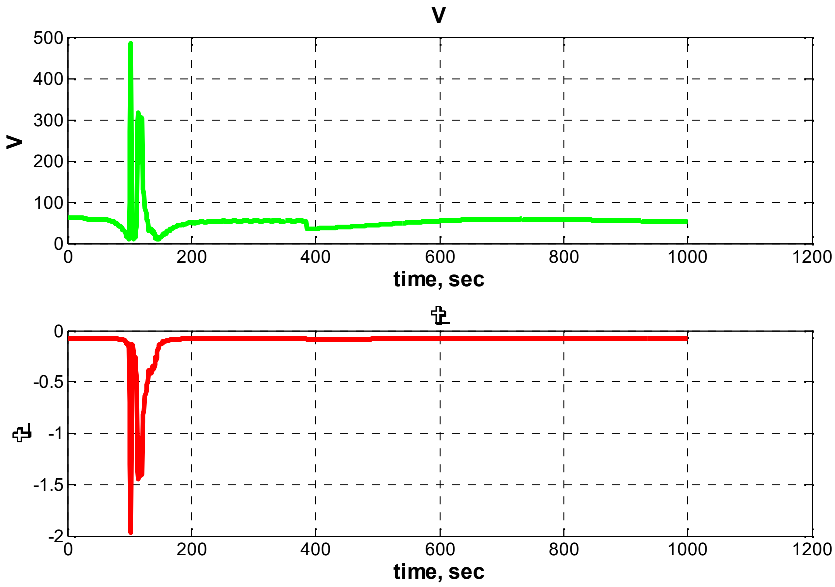

Fig 6: *V* and *V̇* for Lyapunov based and ANFIS based MRAC

Fig. 6 Shows results after stability test and it satisfies positive definite function V and negative semidefinite derivative function condition as per Lyapunov stability criteria. Table1. Shows statistical analysis of error in both case of simulation and shows more accuracy of ANFIS based MRAC. Much less mean square error compared to Lyapunov based MRAC for same model trajectory tracking proves it as beneficial control strategy.

Table 1. Error Statistics for Lyapunov and ANFIS based MRAC

	Lyapunov based MRAC	ANFIS based MRAC
Mean-Error	0.1322	-0.022
Mean Square Error	0.0281	0.0085
Standard Deviation	0.1029	0.0893
Variance	0.0106	0.008

CONCLUSION

Soft computing technique ANFIS based and Lyapunov rule based MRAC technique have been used for simulation. Parameter values for simulation are based on past simulation exercise and as per practical need. Energy balance equations on the vessel and jacket fluids have been used as a model for simulation. Observation of results in both cases reveals strength of both Lyapunov and ANFIS based MRAC. Adaptation parameter is stable and with simulation it has been proved. Statistical analysis shows overall better result for ANFIS based MRAC.

ACKNOWLEDGEMENT

The present work is a part of PhD research work carried out at Nirma University.

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