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Fuzzy Based Learning Control for Shell and Tube Heat Exchanger Process

Ramesh Sekar and Abraham Lincon Srinivasan

Department of Electronics and Instrumentation Engineering, Annamalai University, Annamalai nagar, Tamil nadu, India

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ABSTRACT

Fuzzy Model Reference Learning Control (FMRLC) is an capable technique for the control of nonlinear process. In this paper, a FMRLC is applied in to a non linear shell and tube Heat Exchanger process (STHE). First, the mathematical model of the STHE process is derived and simulation runs are carried out by considering the FMRLC in a closed loop. A similar test runs are also carried out with hybrid fuzzy P+ID Controller and conventional fuzzy for comparison analysis. The results clearly indicate that the incorporation of FMRLC in the control loop in spherical tank system provides a good tracking performance than the hybrid fuzzy P+ID and conventional fuzzy controller.

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INTRODUCTION

Control of nonlinear process is major criteria in the process control industries. This class of nonlinear process show many not easy control problems due to their non-linear dynamic behavior, uncertain and time varying parameters. Especially, control of a Temperature in a shell and tube Heat Exchanger process is vital, because the change in cold water to change in hot water temperature gives rise to the non-linear characteristics. Fuzzy control is a practical alternative for a variety of challenging control applications, since it provides a convenient method for constructing nonlinear controllers via the use of heuristic information.(T.J.Procyk, H.Mamdani,1979) have discussed the advantage of Fuzzy Logic Controllers (FLC) is that it can be applied to plants that are difficult to get the mathematical model. Recently, Fuzzy logic and conventional control design methods have been combined to design a Proportional - Integral Fuzzy Logic Controller (PI - FLC).(K.L.Tang, R.J. Mulholland, 1987) have discussed about the comparison of fuzzy logic with conventional controller.

(Wei Li, 1998) have discussed the Fuzzy P+ID controller and analyze its stability. The main idea of the study is to use a conventional D controller to stabilize a controlled object and the fuzzy proportional (P) controller to improve control performance. According to the stability condition (Wei Li, 1998)and (R.Boukezzoula, S.galichet and L. Foulloy,2003) modify the Ziegler and Nichols' approach to design of the fuzzyP+ID controller since this approach is used in industrial control of a plant with unknown structure or with nonlinear dynamics. When the process is unstable in local region, the controller based on a fixed model will be unreliable and thus the system performance is affected seriously.

To overcome these problems, a "learning" control algorithm is presented in this paper which helps to resolve some of the issues of conventional fuzzy and hybrid fuzzy controller design. This algorithm employs a reference model (a model of how you would like the plant to behave) to provide closed-loop performance feedback for synthesizing and tuning a fuzzy controller's knowledge-base and is referred to as a "Fuzzy Model Reference Learning Controller" (FMRLC) (Adrian-VasileDuka, Stelian Emilian Oltean, Mircea Dulău, 2007), (Scott C. Brown, Kevin M. Passino,1997), (Jeffery R. Layne, Kevin M. Passino, 1993) and (S. Ramesh and S. Abraham Lincon, 2013).

Mathematical Modeling of Shell and Tube Heat Exchanger (STHE):

Figure.1 shows the two different heat exchanger sections namely shell and tube. These sections are further divided into control volumes.The following assumptions were made while designing the mathematical model of shell and tube heat exchanger.

1. The control volumes are small and assumed to have a constant temperature.
2. The heat exchanger is insulated and there is no heat loss from the heat exchanger to the surrounding.

Corresponding Author: Ramesh Sekar, Department of Electronics and Instrumentation Engineering, Annamalai University, Annamalai nagar, Tamil nadu, India
E-mail: sekaramesh06@gmail.com

Shell Control Volume (CV) Energy Balance:

The convection term in heat exchanger is divided into a number of sections called the control volume. The final equation for the energy balance on the shell control volume given in eqn. (1) is equal to the energy gained due to change in temperature plus energy gained by convection.

$$\frac{\rho_s c_s v_s}{N} * \frac{dT_{co}}{dt} = \dot{m}_s c_s (T_{ci} - T_{co}) + \frac{h_s A_s}{N}(T_{ho} - T_{co}) \quad (1)$$

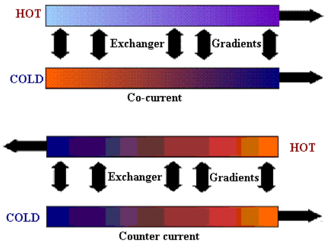

Fig.1: Flow arrangements of Shell and Tube Heat Exchanger (STHE).

Tube Control Volume Energy Balance:

The energy balance on the tube control volume is analogous to the energy balance on the shell control volume. The energy balance equation is developed in the same manner as the equation developed for the shell control volume. The final differential equation for the rate of energy stored in the tube control volume is given by

$$\frac{\rho_t c_t v_t}{N} * \frac{dT_{ho}}{dt} = \dot{m}_t c_t (T_{hi} - T_{ho}) + \frac{h_t A_t}{N}(T_{co} - T_{ho}) \quad (2)$$

The eqns. (1) and (2) are referred as mathematical model of shell and tube heat exchanger and they are solved to get hot water outlet temperature (T_{ho}) by applying cold water inflow rate $\dot{m}_s (C_{in})$. C_{in} is the volumetric flow rate in LPS.

Fuzzy Model Reference Learning Control (FMRLC):

This section discusses the design and development of the FMRLC and it is applied to the STHE system. The following steps are considered for the design of FMRLC and they are direct fuzzy control and Adaptive fuzzy control

In this section, design and development of a FMRLC, which will adaptively tune on-line the centers of the output membership functions of the fuzzy controller determined earlier.

Figure.3 shows the FMRLC as applied to the STHE system. The FMRLC uses a *learning mechanism* that emphasizes

a) Observes data from a fuzzy control system (i.e. *r(kT)* and *y(kT).*
b) Characterizes its present performance, and
c) Automatically synthesizes and/or adjusts the fuzzy controller using rule base modifier so that some

Pre- specified performance objectives are satisfied:

In general, the *reference model*, which characterizes the desired performance of the system, can take any form (linear or nonlinear equations, transfer functions, numerical values etc.). In the case of the Temperature process reference model is shown in the Figure.2.An additional fuzzy system is developed called *"fuzzy inverse model"* which adjusts the centers ofthe output membership functions of the fuzzy controller, which still controls the process, This fuzzy system acts like a second controller, which updates the rule base of the fuzzy controller by acting upon the output variable (its membership functions centers).

The output of the inverse fuzzy model is an adaptation factor *p(kT)* which is used by the rule base modifier to adjust the centers of the output membership functions of the fuzzy controller. The adaptation is stopped when *p(kT)* gets very small and the changes made to the rule base are no longer significant. The fuzzy controller used by the FMRLC structure is the same as the one developed in the previous section.

The *fuzzy inverse model* has a similar structure to that of the controller (the same rule base, membership functions, inference engine, fuzzification and defuzzification interfaces. The inputs of the fuzzy inverse model are

$$ye(kT) = ym(kT) - y(kT)$$
$$yc(kT) = (ye(kT) - ye(KT-T)) / T \quad (3)$$

and the output variable is the adaptation factor *p(kT).*

The *rule base modifier* adjusts the centers of the output membership functions in two stages

1. The active set of rules for the fuzzy controller at time *(k-1)T* is first determine

$$\mu_i^e(e(kT-T)) > 0, i = 1,.....,n$$

$$\mu_j^c(c(kT-T)) > 0, j = 1,.....,m \qquad (4)$$

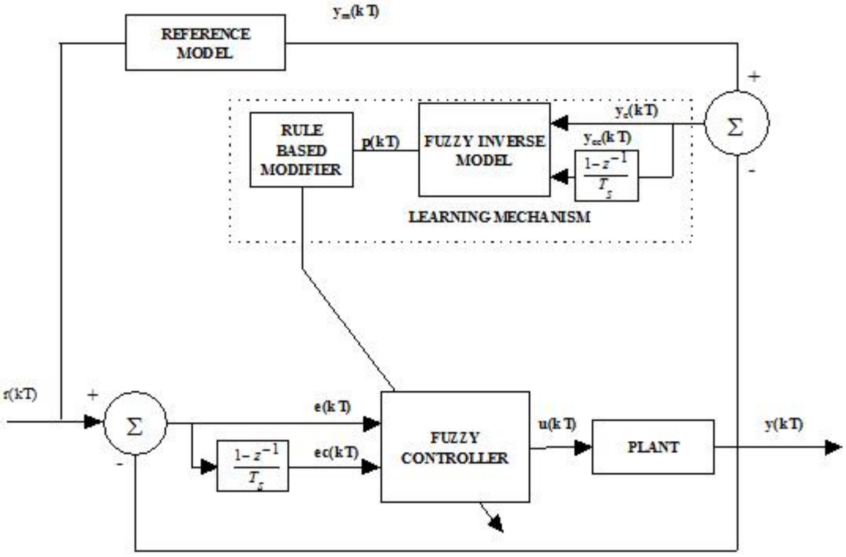

Fig. 2: Fuzzy Model Reference Learning Control.

The pair *(i, j)* will determine the activated rule. We denoted by *i*and *j* the i-th, respectively the *j*-th membership function for the input fuzzy variables error and change in error.

2. The centers of the output membership functions, which were found in the active set of rules determined earlier, are adjusted. The centers of these membership functions (*bl*) at time *kT* will have the following value

$$b(kT) = b(kT - T) + p(kT) \qquad (5)$$

We denoted by *l* the consequence of the rule introduced by the pair *(i, j)*.

The centers of the output membership functions, which are not found in the active set of rules *(i, j)*, will not be updated. This ensures that only those rules that actually contributed to the current output *y(kT)* were modified. We can easily notice that only local changes are made to the controller's rule base.

Hybrid Fuzzy P+ID Controller:

For implementing the block diagram of fuzzy P+ID controller referred Figure.3. Only one supplementary parameter has to be attuned. Consequently, the physical tuning time of the controller can be greatly reduced in comparison with a conventional fuzzy logic controller.

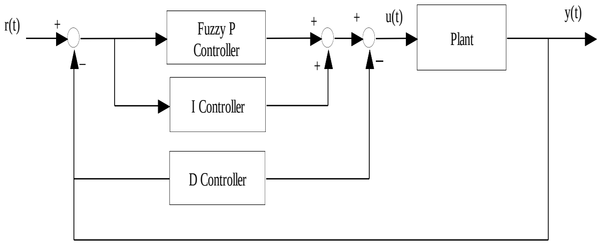

Fig.3: Block diagram of hybrid fuzzy P+ID controller.

Design of Hybrid Fuzzy P+ID Controller:

Design of fuzzy P+ID controller is constructed by replacing the conventional proportional term with the fuzzy one, we propose the following formula:

$$K_P = 0.6K_P(crit) \qquad (6)$$

$$K_I = \frac{2K_P}{T(crit)} \tag{7}$$

$$K_D = (T+2)K_P + K_I T^2 \tag{8}$$

For determination of their parameters. We select the parameter Kd of the derivative controller by using the sufficient stability condition (Wei Li., 1998) instead of the Ziegler and Nichols' formula. This result implies that stability of a system does not change after the conventional PID controller is replaced by the fuzzyP+ID controller without modifying any PID-type controller parameter.

RESULTS AND DISCUSSIONS

Simulated servo responses of shell and tube heat exchanger using FMRLC, Hybrid Fuzzy P+ID and Conventional Fuzzy are presented and discussed in this section. The performance measures of servo responses are given in Table 1. Also the simulated regulatory responses using FMRLC, Hybrid Fuzzy P+ID and Conventional Fuzzy are presented and the performance measures are given in Table 2.

Table 1: Performance index for servo response.

Temperature	FMRLC		Hybrid -fuzzy		Conventional -fuzzy	
	ISE	IAE	ISE	IAE	ISE	IAE
44-45^{o}C	0.02544	2.513	13.28	57.21	41.44	89.35
45-46C	0.02487	2.485	7.267	41.51	23.59	53.7
46-47^{o}C	0.02485	2.486	4.038	29.65	22.6	47.63
47-48C	0.02459	2.473	2.49	21.48	13.77	47.9
48-49C	0.02412	2.448	1.719	15.69	22.04	63.11

The simulated servo responses for step change in setpoint of hot water outlet temperature (T_{ho}) from 44 to 45^{o}C as shown in Fig.4respectively. Initially, the T_{ho} value is maintained at 44^{o}C and then the sudden step change in setpoint is given from 44 to 45^{o}C. It is observed that cold water inflow rate (C_{in}) change in order to maintain T_{ho} at 45^{o}C in simulation.

The regulatory responses of shell and tube heat exchanger are obtained by increase in cold water inflow rate of 0.01 LPS (8%) applied at 350th secondfor the operating points 44^{o}C and 45^{o}C.

Table 2: Performance index for servo regulatory response.

Temperature	FMRLC		Hybrid -fuzzy		Conventional -fuzzy	
	ISE	IAE	ISE	IAE	ISE	IAE
44-45^{o}C	0.02713	7.195	18.21	66.75	25.09	56.71
45-46^{o}C	0.02498	2.491	10.46	49.84	26.1	58.14
46-47^{o}C	0.02501	2.493	5.672	35.67	22.79	48.47
47-48^{o}C	0.02476	2.482	3.212	25.26	12.27	42.03
48-49^{o}C	0.02432	2.459	2.072	18.28	22	63.38

The regulatory responses of shell and tube heat exchanger are obtained by increase in cold water inflow rate of 0.01 LPS (8%) applied at 350th second for the operating points 44^{o}C and 45^{o}C. Also the regulatory responses are obtained by giving +10% sudden changes in hot water inflow rate from nominal flow of 0.0282 to 0.0310 LPS at 350th second.

Due to increase in cold water inflow rate of 0.01 LPS (8%) at the operating point of 44^{o}C, the hot water outlet temperature (T_{ho}) value is decreased from nominal value of 44^{o}C to 43.7^{o}C.The FMRLC controller takes the necessary action to bring back the T_{ho} value from 43.7^{o}C to 44^{o}C by decreasing the cold water inflow rate from 0.06365 to 0.0535 LPS. This is achieved by the FMRLCcontrollerat 250th secondfrom the load applied point at 350th second. Also the different operating points (45ºC,46ºC, 47ºC & 48ºC)are also carried out and their response are traced in Figures. 5 - 9 and performances indices are summarized in the same Tables1and 2.It is observed that, the FMRLC algorithm gives an excellent performance than the other two.From the Tables 1 and 2, it is observed that FMRLC control algorithm provides satisfactory performance in the servo and servo regulatory cases than the other control strategies

Conclusion:

This paper, a Fuzzy Model Reference Learning Control (FMRLC) is applied in to a nonlinear STHE system.Simulation runs are carried out by considering the FMRLC algorithm, hybrid fuzzy and conventional fuzzy controller in a closed loop. The results clearly indicate that the incorporation of FMRLC in the control loop in STHE system provides a superior tracking performance than the hybrid fuzzy and conventional fuzzy controller.

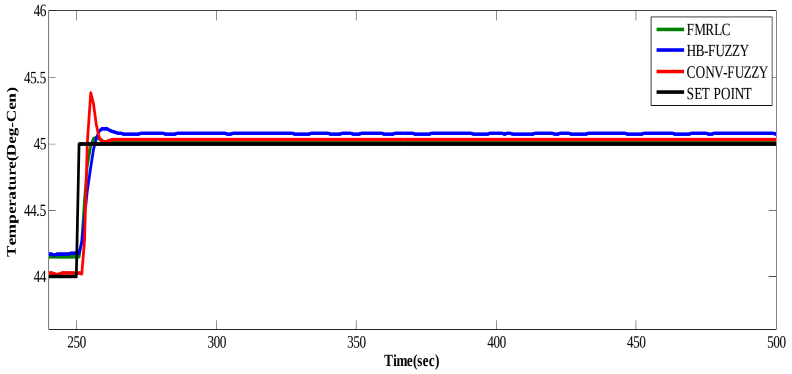

Fig.4: Servo Response of STHEat 44ºC operation point.

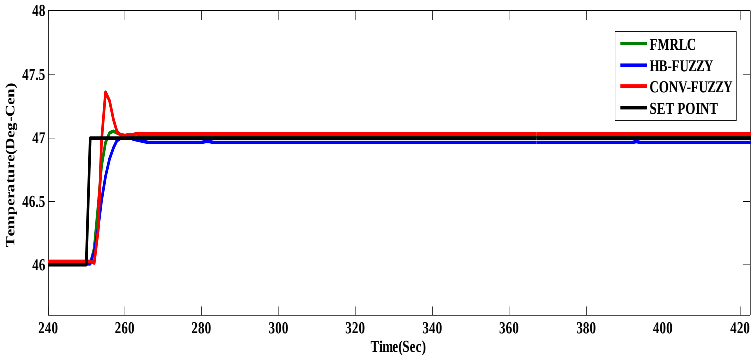

Fig 5: Servo Response of STHE at 46ºC operation point.

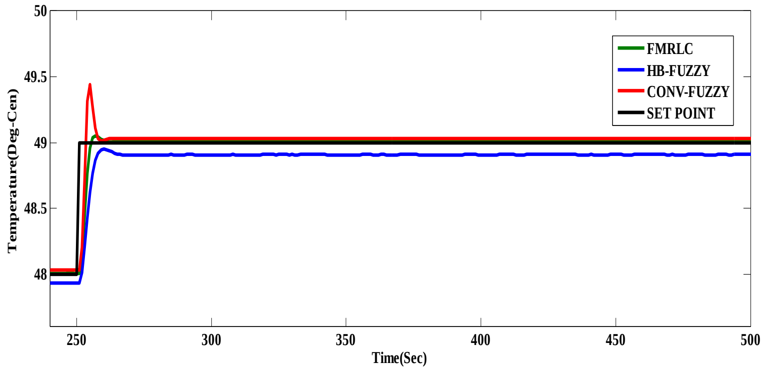

Fig.6: Servo Response of STHE at 48ºC operation point

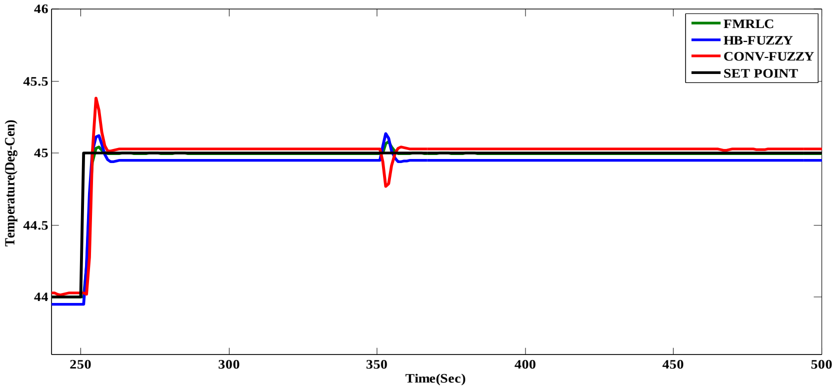

Fig.7: Regulatory Response of STHE at 44ºC operating point.

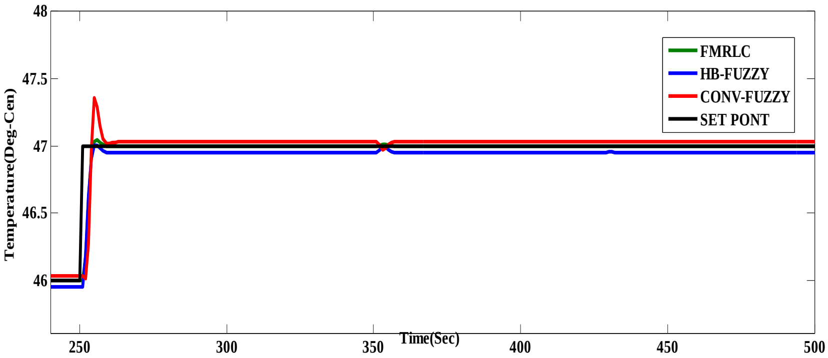

Fig.8: Regulatory Response of STHE at 46ºC operating point.

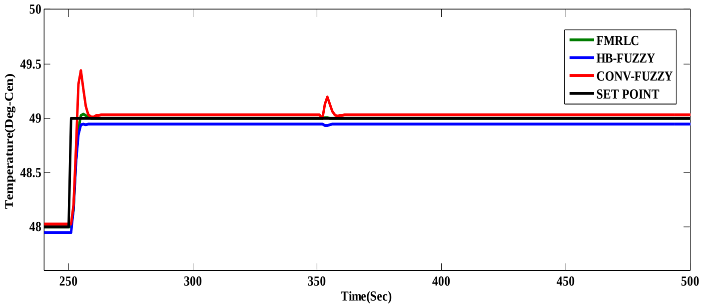

Fig. 9: Regulatory Response of STHE at 48ºC operating point.

REFERENCES

Adrian-Vasile Duka, Stelian Emilian Oltean, Mircea Dulău, 2007. Model Reference Adaptive vs. Learning Control for the Inverted Pendulum. A Comparative Case Study. CEAI., 9(3): 67-75.

Boukezzoula, R., S. Galichet and L. Foulloy, 2003. Nonlinear internal model control: application of inverse model based fuzzy control. IEEE Transactions on Fuzzy Systems, 11(6): 814- 829.

Jeffery Layne, R. and M. Kevin Passino, 1993. Fuzzy Model Reference Learning Control for Cargo Ship Steering. IEEE Control Systems Magazine, 13: 23-34.

Procyk, T.J. and H. Mamdani, 1979. A Linguistic self-organizing process controller. Automatica 15: 15-30.

Ramesh. S and S.Abraham Lincon, 2013. Fuzzy Model Based Learning Control for Spherical Tank Process. International Journal of Engineering Research and Applications (IJERA), 3(6): 619-623.

Ramesh, S. and S. Abraham Lincon, 2013. Fuzzy model Reference learning controller for nonlinear Spherical Tank process. International Journal of Engineering Trends and Technology (IJETT), 4(10): 4459-4465.

Scott Brown, C. and M. Kevin Passino, 1997. Intelligent Control for a RobaticAcrobot. Methods and Applications of Intelligent Control, 16: 357-399.

Tang, K.L. and R.J. Mulholland, 1987. Comparing fuzzy logic with classical controller design. IEEE Transaction on systems, Man and Cybernetics, 17(6): 1085-1087.

Wei Li, 1998. Design of a Hybrid Fuzzy Logic Proportional Plus Conventional Integral-Derivative Controller. IEEE transactions on fuzzy systems, 6(4): 449-463.