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Research Article

CHATTERING FREE FUZZY SLIDING MODE CONTROL APPROACH FOR NONLINEAR ISOTHERMAL CSTR

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ABSTRACT

This paper presents sliding mode controller for an isothermal continuous stirred tank reactor, which is used to carry out chemical reactions in an industry. Isothermal continuous stirred tank reactor is one of the types of reactor which operates at a constant temperature. Variable structure control with sliding mode can provide fine control performance and robustness. However, chattering phenomenon introduced due to discontinuous switching gain limits their applications. To achieve precise tracking performance with reduced chattering effect, fuzzy sliding mode control is introduced. This nonlinear controller can eliminate the chattering problem that emerges in the conventional sliding mode control. Simulation and experiment results indicate that proposed schemes not only improve the tracking performance but also ensure chattering reduction.

Keywords: *Isothermal CSTR, Sliding Mode Control, Fuzzy Sliding Mode Controller, Chattering Cancellation*

INTRODUCTION

Chemical processes show dynamic behavior during start-up, shutdown, and when upsets occur under steady state conditions. Mathematical modeling, simulation, and control of these processes are relatively difficult, because of the nonlinear nature of these processes and the activation and tuning difficulties of the controllers. This difficulty has limited the usage of nonlinear models to regions and systems where the model obtained is reliable.

Sliding mode control (SMC) is a powerful control method to solve the tracking control of uncertain nonlinear systems. It has the advantages of good robustness against model uncertainties and external disturbances (Ho *et al.*, 2009). The key idea in SMC is to guide the states of the controlled system to be located on a designed surface (the sliding surface) and keeping them there with a shifting law (Roopaei and Jahromi, 2009). The most important disadvantage of SMC is chattering or high frequency oscillations. This phenomenon can cause lots of damages in plant dynamics. A solution for overcome this problem is combination of nonlinear controller with intelligent methods such as fuzzy sliding mode control (FSMC). The FSMC has the advantages of both SMC and FLC (Chen and Chang, 1998].

Sign function in SMC law causes chattering that undesirable as it degrades the control performance by motivating the unmodeled system dynamics (Miroslav *et al.*, 2002, Slontine and Li, 1991). During past decades, numerous techniques had been studied for chattering reduction. Boundary layer (Slontine and Li, 1991) approach can reduce chattering but at the cost of robustness. Hence, it is necessary to get the compromise between robustness and chattering reduction. Eloi, 2001, presented the concept of quantitative feedback theory (QFT); Pushkin, 1996, exploited integral action inside fixed boundary layer for chattering reduction. In recent years, fuzzy logic (Ha *et al.*, 2001, Lianga and Su, 2003, Sadati and Ali, 2004) was widely used to reduce chattering effect and improve the tracking performance.

This research work presents fuzzy sliding mode control (FSMC) with the objectives of reducing the chattering amplitude and achieving precise tracking performance for nonlinear Isothermal CSTR system.

Dynamic Model of an Isothermal CSTR

Isothermal CSTR is a type of CSTR which is operating at a constant temperature. The volume is also assumed to be constant. The reaction scheme consists of the following irreversible reactions. The feed stream contains only component A. Block diagram of an Isothermal CSTR is shown in Figure 1.

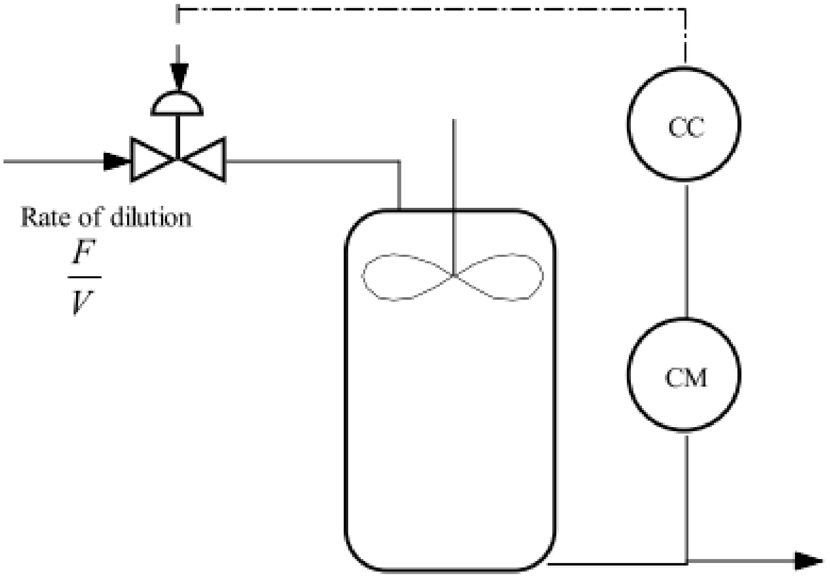

Figure1: Feedback control mechanism for concentration control of Isothermal CSTR

Here CM represents the measurement of concentration and CC represents the concentration controller. Two simplified dynamic functional equation is represented as (Vishnoi, *et al.*, 2012):

$$\begin{aligned}\frac{dC_A}{dt} &= \frac{F}{V}(C_{AF} - C_A) - k_1C_A - k_3C_A^2 \\ \frac{dC_B}{dt} &= \frac{F}{V}(-C_B) + k_1C_A - k_2C_B\end{aligned} \tag{1}$$

Where:

C_A	Concentration of A
C_B	Concentration of B
C_{As}	Steady state concentration of A
C_{Bs}	Steady state concentration of B
C_{AF}	Steady state feed concentration
F	Input
k_1, k_2, k_3	Rate constants of reaction

The values of the parameters are shown in Table I.

Table I: Parameter Value

Parameter	**Value**	**Unit**
k_1	0.833	min^{-1}
k_2	1.66	min^{-1}
k_3	0.166	min^{-1}
C_{AF}	10	$gmolL^{-1}$
V	1	L

Sliding Mode Controller

The most important task is to design a switched control that will drive the plant state to the switching surface and maintain it on the surface upon interception. A Lyapunov approach is used to characterize this task.

Consider a nonlinear system:

$$\dot{x} = f(x,u,w) \tag{2}$$

Where x is state vector, u is input and w is uncertainty whit known limits. The tracking error is defined as follow:

$$e_i = x_i - x_{id} \tag{3}$$

The choice of the sliding surfaces is based upon the tracking errors:

$$S = \sum c_i e_i \tag{4}$$

Where the coefficients c_i should be chosen such that the poles of characteristic polynomial (Eq.5) have negative real part:

$$P(\lambda) = \sum \lambda^i c_i \tag{5}$$

Consider a positive Lyapunov function as Eq.6. Controller should be designed to satisfy Eq.7.

$$V = \frac{1}{2}S^2 \tag{6}$$

$$\dot{V} = S\dot{S} \prec 0 \tag{7}$$

Here for described system in Eq.1, the equations 3-4 rewrite as follow:

$$\begin{aligned} e_1 &= C_A - C_{Ad} \\ e_2 &= C_B - C_{Bd} \end{aligned} \tag{8}$$

$$S = e_1 + e_2 \tag{9}$$

SMC law is obtained in Eq.10

$$F = \frac{V}{C_{AF} - C_A - C_B}(k_3 C_A^2 + k_2 C_B + Ksign(S)) \tag{10}$$

Fuzzy Sliding Mode Controller

To avoid control chattering, a boundary layer or intelligent method can be used to smooth out the control discontinuity caused by sign(s) in the SM control low. In order to overcome this problem, one can use the concept of SMC and FLC. This approach has been used in various engineering applications. In this section, a procedure by which FSMC can be designed is described.

To comply with the need for fuzzy inference values to be between -1 and 1, the inputs of the fuzzy controller, S and $\dot{S}$, are scaled by the coefficients g_1 and g_2 respectively. On the other hand, since the output of the fuzzy controller (Du) also lies between -1 and 1, it should be multiplied by g_3 to result in a change of plant input.

The membership functions that are recommended to the inputs and the output are shown in Figure 2 & 3. Figure 4 shows the surface using inputs, outputs and rules. With this choice of membership functions and fuzzy rules, the fuzzy controller decreases the chattering phenomenon, otherwise the performance improved, see Figure 5-8. This is another advantage of the present work.

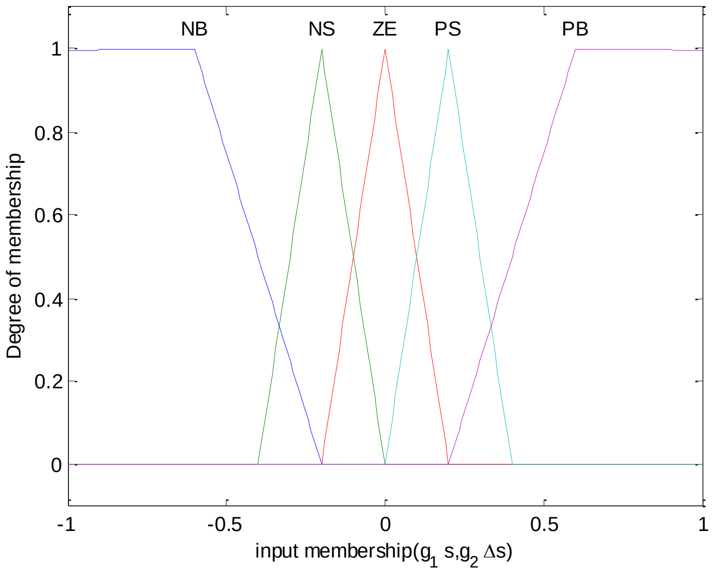

Figure 2: Input memberships

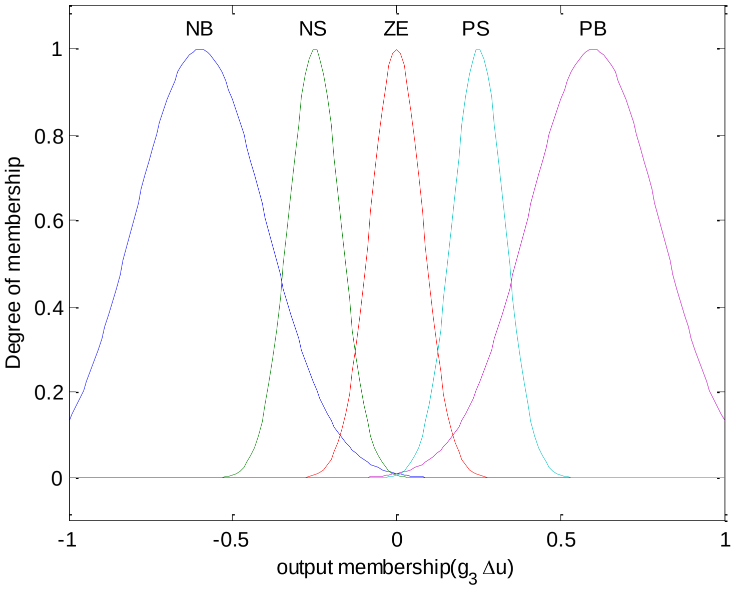

Figure 3: Output membership

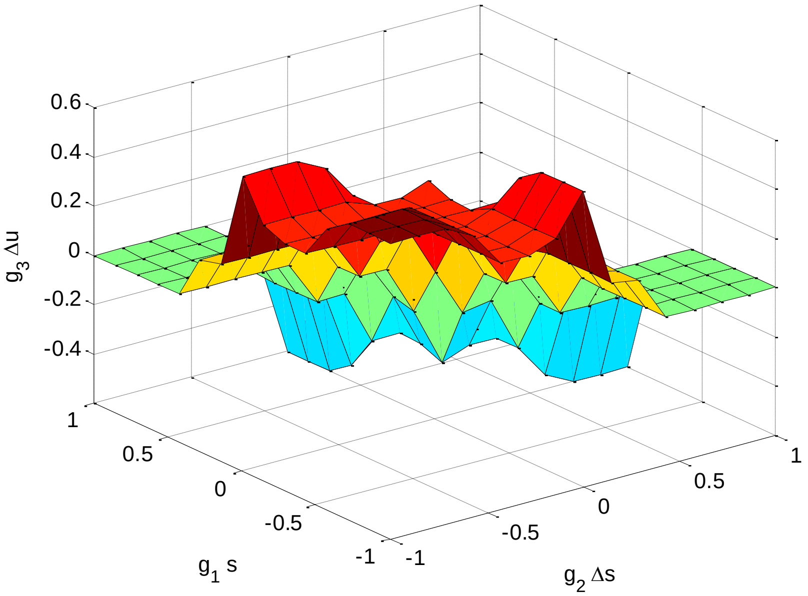

Figure 4: Surface of fuzzy set

Simulation Result

In order to evaluate the performance of the proposed approaches, simulation has been done. Initial values for states assumed to be $[3\ 1.1]^T$, g1, g2 and g3 are respectively 3.5, 0.1 and 0.55. Also K in SMC had been chosen 0.5. Results are compared to indicate that fuzzy sliding mode controller has more benefits in both regulation and chattering elimination.

Figure 5 shows that states reach their goal using both controller, but as it is shown in Figure 6 & 7 FSMC redound less error in comparison of SMC.

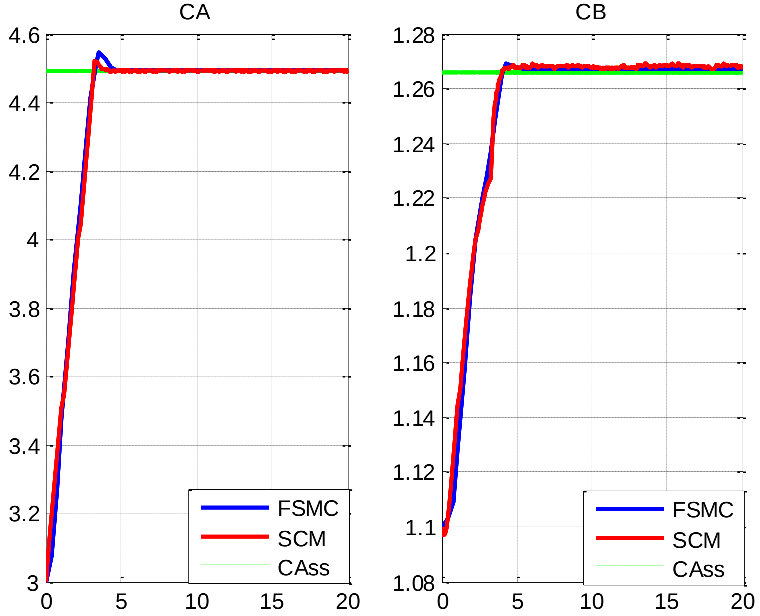

Figure 5: Actual and desired trajectory (CB) left (CA)

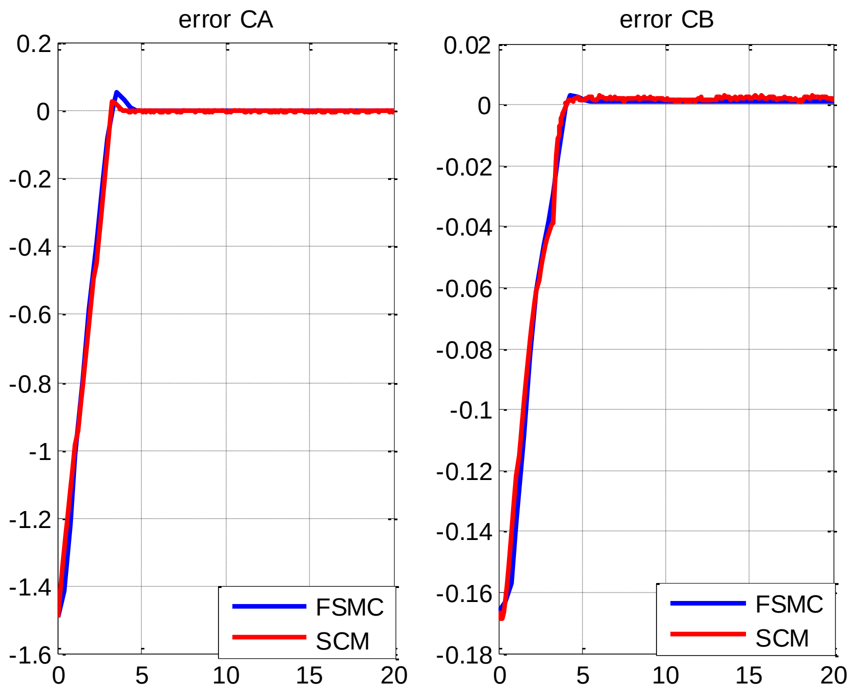

Figure 6: States' error of system right (CB) left (CA)

Also as it is shown in Figure 8 using FSMC helps in cancellation of chattering phenomenon, which is one of most important challenges in control engineering.

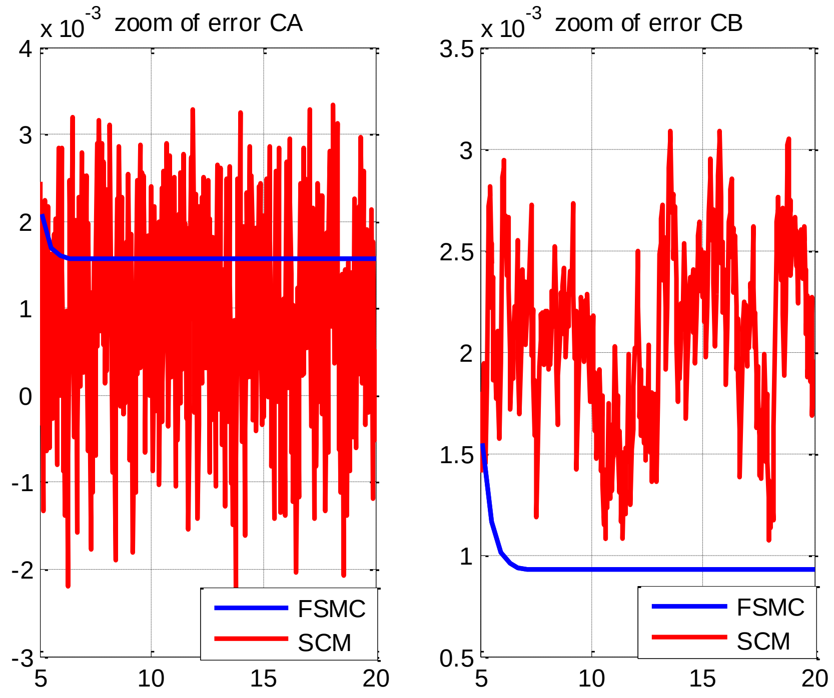

Figure 7: Zoom of states' error

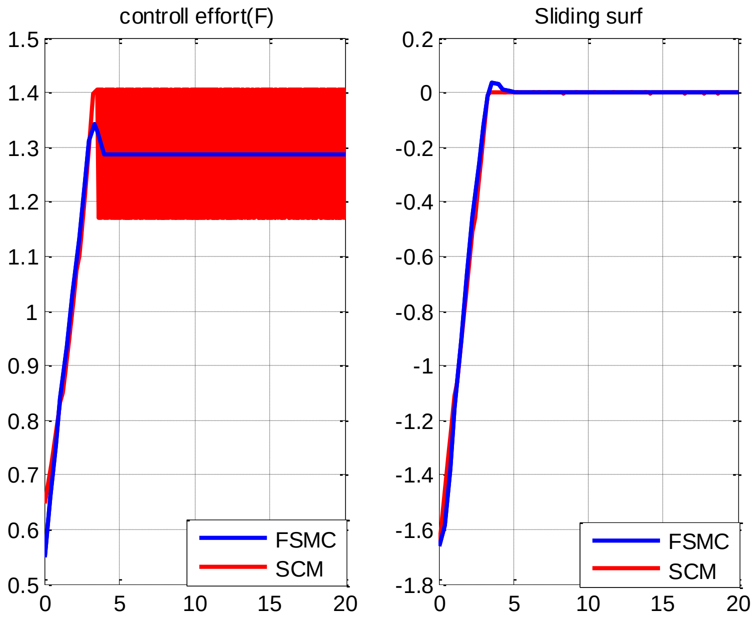

Figure 8: Control effort (left) and sliding surface (right)

CONCLUSION

In This paper, the novel chattering free SMC is proposed. Since the chattering in the SMC had been induced by sign function in control input, fuzzy sliding mode control (FSMC) as a robust and intelligent nonlinear control technique is proposed to control process with severe nonlinearity and chattering free. To verify the performance of the proposed controller, two simulation results for an Isothermal CSTR system is done. The simulation results confirmed the effectiveness of the proposed method.

REFERENCES

Chen CL and Chang MH (1998). Optimal design of fuzzy sliding-mode control: A comparative study. *Fuzzy Sets and Systems* **93** 37-48.

Ha QP, Nguyen HQ, Rye DC and Durrant Whyte HF (2001). Fuzzy sliding mode controllers with applications. *IEEE Transactions on Industrial Electronics* **48**(1) 38-46.

Ho HF, Wong YK and Rad AB (2009). Adaptive fuzzy sliding mode control with chattering elimination for nonlinear SISO systems. *Simulation Modelling Practice and Theory* **17** 1199-1210.

Kachroo P (1996). Chattering reduction and error convergence in the sliding mode control of a class of nonlinear systems. *IEEE Transactions on Automation Control* **41**(7) 1063-1068.

Lianga CY and Su JP (2003). A new approach to the design of a new fuzzy sliding mode controller. *Fuzzy Sets and Systems* **139** 111-124.

Miroslav M, Vlastimir N and Dragan A (2002). Position control of an electro hydraulic servo system using sliding mode control enhanced by fuzzy PI controller. *Mechanical Engineering* **1**(9) 1217-1230.

Roopaei M and Zolghadri Jahromi M (2009). Chattering-free fuzzy sliding mode control in MIMO uncertain systems. *Nonlinear Analysis* **71** 4430-4437.

Sadati N and Ali T (2004). Chattering-free adaptive fuzzy sliding mode control. *Proceeding of the 2004 IEEE Conference on Cybernetics and Industrial Systems, Singapore* 29-34.

Slontine JJ and Li W (1991). *Applied Nonlinear Control* (Prentice Hall, Englewood cliffs, New Jersey).

Taha EZ, Gemunu SH and Yildirim H (2001). Quantitative feedback theory (QFT) for chattering reduction and improved tracking in sliding mode control. *Proceedings of the American Control Conference* 5004-5009.

Vishal Vishnoi, Subhransu Padhee and Gagandeep Kaur (2012). Controller Performance Evaluation for Concentration Control of Isothermal Continuous Stirred Tank Reactor. *International Journal of Scientific and Research Publications* **2**(6).