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Scientific paper

A Reactor Fuzzy Control System

Maja Ivanović-Knežević and Snežana Krstić
University of Belgrade, Faculty of Technology and Metallurgy,
11000 Belgrade, Karnegijeva 4, Serbia
e-mail:majai@tmf.bg.ac.rs,snezana@tmf.bg.ac.rs

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Abstract

This paper studies the feasibility of using a nonlinear fuzzy logic control for chemical processes exemplified by a continuous stirred tank reactor. The inputs were reactant rates and initial concentrations. The outputs were product rate and concentration of the species. The dynamic response of the control loop to a random disturbance with varying amplitude of the reactants flow was examined. Some inverse models were investigated. The fuzzy logic controller improves quality control, determines optimum set points, updates planning models, and troubleshoots day-to-day operating problems. This capability also allows the fuzzy controller to adapt a system which varies slowly over time. The main contribution of this paper is the nonlinear fuzzy control of the chemical reactor.

Keywords: Fuzzy control, reactor dynamic response, set points, random disturbance

1.Introduction

Recently, fuzzy logic controllers have been successfully applied to a wide range of industrial processes as well as consumer products, and show certain advantages over the conventional PI and PID controllers. On the other hand, although, fuzzy controllers have been extensively studied in control engineering(Zadeh,1983;Corn,1993;Bulsary et.al.,1993;Savković-Stevanović et.al.,2008; Savković-Stevanović1992;). there are still rather few theoretical proof that can explain why fuzzy logic controller can achieve better performance.

The fuzzy control system in this paper based on qualitative fuzzy variables was used for reducing the number of membership parameters and input/output rules as much as possible.

2. Fuzzy logic variables and functions

Unlike binary logic, fuzzy system do not restrict a variable to be a member of a single set, but recognize that a given value may fit to varying degrees, into several. It incorporate the imprecision inherent in many real world systems, including human reasoning, by allowing linguistic variables classification such as big, high, slow, medium, near zero, or too fast.

Fuzzy systems operate by testing variables with IF-THEN rules, which produce appropriate responses. Each rules then weighted by a degree of fulfillment of the rule invoked, this is a number between 0 and 1, and may be thought of as probability that a given number is considered to be included in a particular set. A wide variety

of shapes is possible fulfillment functions, with triangles and trapezoids being the most popular. Fulfillment functions for this study were of the form:

$$\mu(x,m,s,p) = \exp(-(|x-m|)/s)^{p}) \quad (1)$$

where m, s, and p are user chosen parameters and x is the values to be tested. The function was chosen because of its flexibility, by changing m, s, and p whole families of different functions can be obtained. For p=2 this is an non normalized Gaussian density with mean m, and standard deviation s. A sample of the functions obtains by varying the p parameter. The system operates by testing rules of different types.

IF x_i is high AND y_i is low THEN u_{ij} is slow or fast.

The degree of fulfillment for such a rule in this study was chosen to be the minimum of the degrees of fulfillment of the antecedent clauses.

The total output of the control system is calculated as weighted sum of the responses to all *n* rules outputs.

3. The case study

A chemical stirred tank reactor was used for an irreversible reaction (Savković-Stevanović et.al.,2005; Savković-Stevanović et.al.,2003)(Figure 1).

$$aA + bB \xrightarrow{k} cC \quad (2)$$

It is assumed the pseudo first order reaction is carried out in a single perfectly mixed reactor as shown in Figure 1. A dynamic model for the reactor control can be obtained using of the first principle modeling approach. Eq.(2) can be restarted in the following equivalent form $\nu_a A + \nu_b B + \nu_c C = 0$ where ν_a =-1, ν_a =-b/a=-1 and ν_c =c/a=1 By setting material and energy balances, and using the relationship for specific chemical reaction rate constant $k = k_0 e^{-E/RT}$, one obtains.

Total material balance:

$$F_0 - F = \frac{dV}{dt} \quad (3)$$

Overall heat transfer between process at the temperature T and jacket fluid at the temperature T_j:

$$Q = UA_H (T - T_j) \quad (4)$$

Components balances:

$$F_0 c_{A0} - F c_A - V k_0 e^{-E/RT} c_A c_B = -\frac{d}{dt}(V c_A) \quad (5)$$

$$F_0 c_{B0} - F c_B - V k_0 e^{-E/RT} c_A c_B = -\frac{d}{dt}(V c_B) \quad (6)$$

$$V k_0 e^{-E/RT} c_A c_B - F c_C = \frac{d}{dt}(V c_C) \quad (7)$$

Energy balance,

$$\rho c_p (F_{0A} T_0 + F_{0B} T_0 - FT) - \Delta H_r (V k_0 e^{-E/RT} c_A c_B) + UA_H (T_J - T) = \rho c_p \frac{d}{dt}(VT) \quad (8)$$

and jacket energy balance,

$$\rho_J F_J C_{pJ} (T_{J0} - T_J) + UA_H (T_J - T) = -\rho_J V_J C_{PJ} \frac{dT_J}{dt} \quad (9)$$

where F_0 is inlet flow, F is outlet flow, c_{A0} and c_{B0} are the inlet concentration, c_A, c_B, c_C, are the current species concentration, V is volume of the liquid reaction mixture, T is the temperature the liquid reaction mixture, k_0 is acceleration factor, E is energy activation, R universal gas constant and T_J is the temperature of the heating fluid, F_J flow rate of heating fluid. Q is heat of transfer rate, A_H is heat transfer area, U is overall heat transfer coefficient, ρ is density of the liquid reaction mixture, ρ_J is density of heating fluid, Cp_J is capacity of the heating fluid and C_p is capacity of the reaction mixture at the constant pressure. The operation parameters of the chemical stirred tank reactor are given in Table 1.

Table 1.The steady state operation parameters of the chemical stirred tank reactor

Name	Value
Reaction volume V	$1.00 m^3$
Outlet flow rate F	$2.00 m^3/s$
Current temperature T	87.10 ̊C
Current concentration c_A	$0.008 mole/m^3$
Current concentration c_C	$0.880 mole/m^3$
Current concentration c_B	$0.005 mole/m^3$
Reactant A initial flow rate F_{0A}	$2.000 m^3/s$
Reactant B initial flow rate F_{0B}	$1.000 m^3/s$
Current temperature T_J	37.5 ̊C

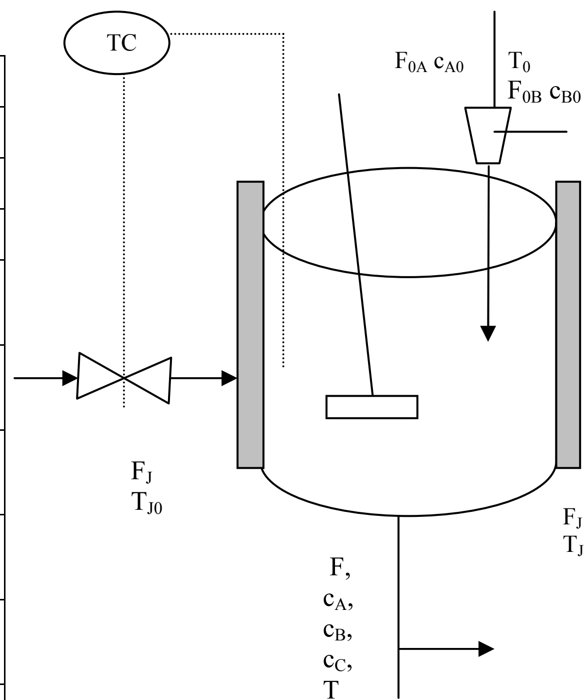

Figure 1. Scheme of the chemical stirred tank

The step disturbance was incorporated to the inlet flow rate to the reactor and cooling water stream flow. The temperature can be selected as a manipulative variable. The control objective was to operate tank as close to the required product composition values.

Hydraulic relationship between reactor holdup and the flow out of the reactor is defined. It is assumed that a level controller changes the outflow in direct proportion to the volume in the reactor. The outflow increases as the volume builds up in the reactor and decreases as the volume drops. The outflow is shut off completely when the volume drops to a minimum value V_{min}.

$$F=K_V (V-V_{min}) \qquad (10)$$

where K_V is proportional constant. The level controller is a proportional feedback controller.

3. The fuzzy control model

The qualitative variables the inlet and outlet reaction mixture flow, the inlet and outlet concentration and the reaction temperature as well as temperature in the jacket were considered. The input variables are the initial reactant flow rate and the initial reactant composition, the cooling water flow in the jacket (which assumed constant) and output variables reaction mixture flow, product composition, temperature of the reactor mixture and temperature in the jacket are identified.

The process can be approximated by a first order plus dead time function based control by conventional proportional integral law.

The qualitative model for systematic cause-event analysis was made, and variables discrete state were defined.

Initial reactant flow (low, medium, high)
product flow(low, medium, high)
cooling fluid flow (low, medium, high)
reaction volume level(low, medium, high)

concentration (increasing, slow increasing, normal, slow decreasing , decreasing).
temperature (increasing, slow increasing, normal, slow decreasing, decreasing)

From equation (1) for p=1 the meaning of the linguistic values is defined by LL-RR-type membership.function:

$$\mu(x) = \begin{cases} LL(B_1 - x)/(B_1 - a) & IF \quad x < B_1 \\ 1 & IF \quad B_1 < x > B_2 \\ RR(x - B_2)/(\beta - B_2) & IF \quad x > B_2 \end{cases} \qquad (11)$$

where x is current fuzzy value. B_1 and B_2 are the maximum values of the fuzzy number, α and β are the left and right spreads, and LL-RR are the appropriate chosen functions.

The control system can be defined with two inputs and one outputs. A systematic cause – event analysis is defined by fuzzy rules according to the equation:

IF ($F_1 = B_1$) AND ($F_2 = B_2$) THEN V is Vmin (9)

Some fuzzy production rules have shown in the section 5 for extension control system.

As manipulative variables were considered reactor outlet flow and reaction temperature T. Disturbances were made in inlet rate F_0 and cooling water inlet flow F_J. As controlled variables were considered concentration c_C.

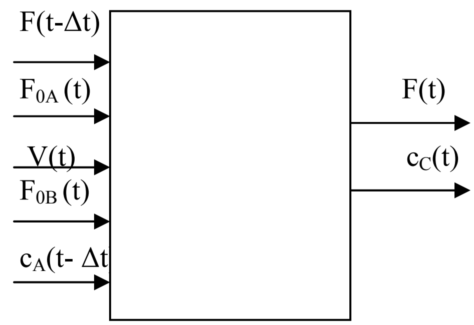

Figure 2. An inverse model to reactor outlet flow loop

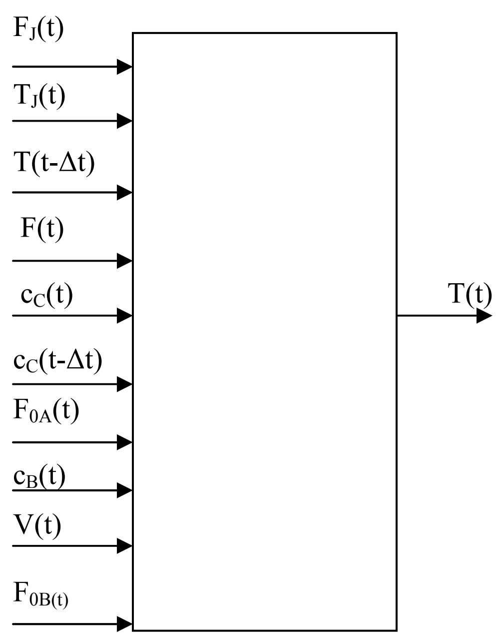

Figure 3. An inverse model to temperature loop

4 Some rules sets for reactor control system

An advanced fuzzy controller was generated using set rules as following:

Rule set number 1:
IF outlet flow $F(t)$ is high AND inlet flow $F_{0A}(t)$ is high AND inlet flow $F_{0B}(t)$ is high THEN product concentration $c_C(t+\Delta t)$ is normal.
Rule set number 2:
IF outlet flow $F(t)$ is medium AND inlet flow $F_{0A}(t)$ is low AND inlet flow $F_{0B}(t)$ is medium THEN product concentration $c_C(t+\Delta t)$ is slow decreasing.
Rule set number 3.
IF outlet flow $F(t)$ is medium AND inlet flow $F_{0A}(t)$ is high AND inlet flow $F_{0B}(t)$ is low THEN product concentration $c_C(t+\Delta t)$ is slow decreasing.
Rule set number 4.
IF outlet flow $F(t)$ is low AND inlet flow $F_{0A}(t)$ is high AND inlet flow $F_{0B}(t)$ is high THEN product concentration $c_C(t+\Delta t)$ is increasing.
Rule set number 5:
IF outlet flow $F(t)$ is medium AND inlet flow $F_{0A}(t)$ is low AND inlet flow $F_{0B}(t)$ is low THEN product concentration $c_C(t+\Delta t)$ is decreasing.
Rule set number 11:
IF temperature T_J is low THEN temperature T is low AND product concentration $c_C(t+\Delta t)$ is decreasing.

5. Results and discussion

The dynamic response of the control loop to a random disturbance with varying amplitude of the reactants flow rates was examined.

The process inputs and outputs are considered during the simulation. The random disturbance were used for control. The investigation is carried out during a time period from 0 to 1200s.

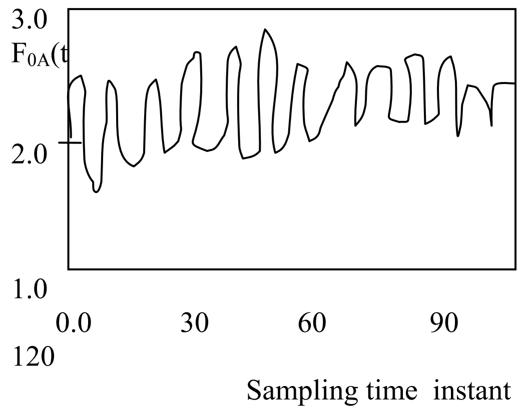

Figure 4. Random disturbance in the reactant A flow rate $F_{0A}(t)$

Figure 4. shows disturbance in the reactant A flow rate $F_{0A}(t)$. In Fig. 5 disturbance in the reactant B flow rate $F_{0B}(t)$ has shown.

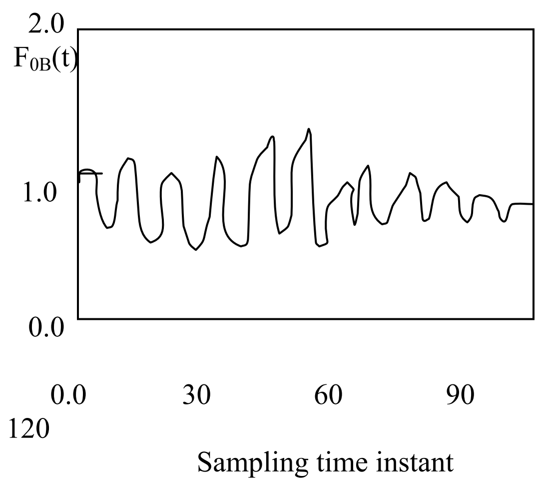

Figure 5. Random disturbance in the reactant B flow rate $F_{0B}(t)$

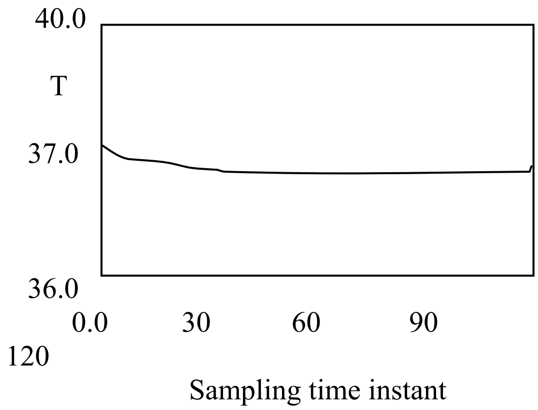

Figure 6. Dynamic response of the temperature

T to disturbance in inlet flow rate $F_{0A}(t)$

The obtained control results are shown in Figure 6. –Figure 7. Figure 6 shows response of the temperature T to the disturbance in inlet flow rate $F_{0A}(t)$. Response of the product composition to the disturbance in the inlet flow rate $F_{0A}(t)$ is shown in Figure 7.

6. Conclusions

This paper was studied fuzzy modeling for chemical reactor control. An advanced fuzzy control model was derived. The fuzzy controller application was illustrated to the chemical stirred tank reactor with irreversible the pseudo first order reaction. Dynamic responses were studied for random disturbance.

The developed model based on fuzzy logic, for stirred tank reactor, performed well for the wider operating ranges considered and can be used with confidence for the on-line measurement. A fuzzy logic controller was illustrates to successfully control the system and to exhibit desirable robustness properties. The system reaches the set point faster, with less overshoot, hence the setting time is the shortest, especially for instable region. Results of this investigation can be applied in the other domain such as pharmaceutical engineering.

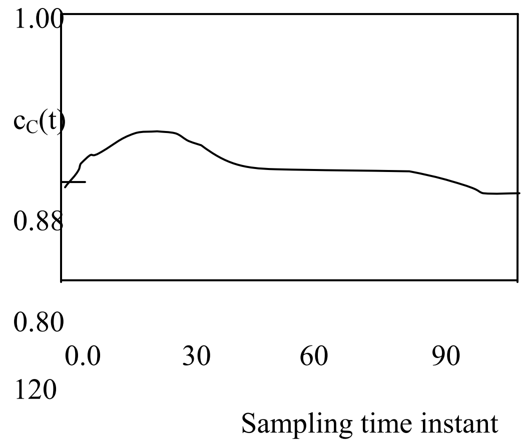

Figure 7. Response of the product concentration for disturbance in inlet flow rate $F_{0A}(t)$

Results of this investigation can be applied in the other domain such as pharmaceutical engineering.

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Notation

A-first reactant
A_H-heat transfer area, m^2
B- second reactant
B_1-maximum limit
B_2-maximum limit
C-product
c - current concentration, mole/ m^3
C_p – heat capacity, J/mole degree
E -energy activation, J/mole
F-flow rate, m^3/s
L-left appropriate function
k-specific chemical rate constant,s^{-1}
k_0 -acceleration factor
Q - heat of transfer rate, J/s
R-universal gas constant, J/mole K
T-reaction mixture temperature
U-overall heat transfer coefficient, J/ m^2 s degree
u-manipulative variable
V-volume, m^3
w- weight factor

e-error

Greek Symbols
Δe- change of error
μ(x)- membership function
Δt- time interval,s

Index
A-reactant 1
B-reactant 2
C-product
H-heat
0-inlet condition
J-jacket
min-minimum

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IZVOD

REAKTORSKI REGULACIONI SISTEM U USLOVIMA NEIZVESNOSTI

Maja Ivanović-Knežević and Snežana Krstić
Tehnološko-metalurški fakultet Univerziteta u Beogradu
11000 Beograd, Karnegijeva 4, Srbija
e-mail:majai@tmf.bg.ac.yu,snezana@tmf.bg.ac.yu

U ovom radu proučavana je izvodljivost korišćenja fazi logičke regulacije za hemijske procese na primeru kontinualnog reaktora sa mešanjem. Ulazi su protoci reaktanata i početne koncentracije. Izalzi su protoci proizvoda i koncentracije vrsta. Dinamički odziv regulacione petlje na slučajan poremećaj sa promenljivom amplitudom na protok reaktanata je ispitivan. Istraživano je nekoliko inverznih modela. Fazi logički regulator poboljšava kvalitet regulacije, određuje optimum početnih tačaka, ažurira planirane modele i otklanja operativne probleme iz dana u dan. Ova sposobnost dozvoljava fazi regulatoru da adaptira sistem koji varira sporo sa vremenom.

Ključne reči: regulacija u uslovima neizvesnosti, dinamički odziv reaktora, početni set,slučajni poremećaj