KON 426E
Intelligent Control Systems
Assignment 2

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2021-2022 Spring

Neural Network Controller

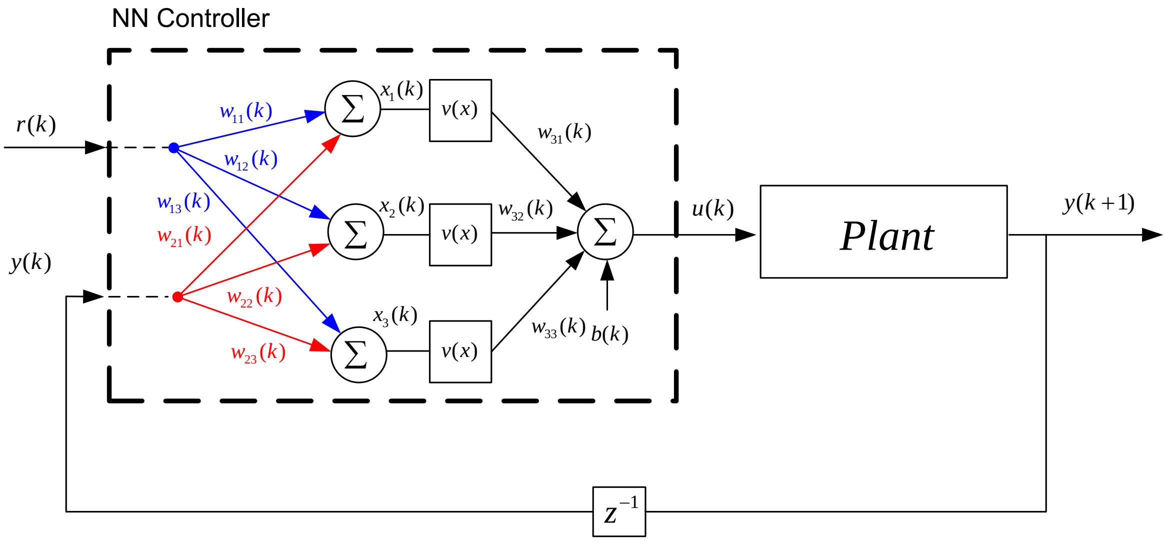

Fig.1 Neural Network Structure

Neural Network structure can be used as a controller directly as in fig.1. The performance of the controller is going to be evaluated on the following nonlinear time-varying plant :

$$y(k+1) = \frac{1.2(1-0.8e^{-0.1k})\ y(k)}{1+\ y^2(k)} + u(k) \qquad \textbf{(1)}$$

The initial values of weights in NN controller are initialized as in table 1.

Table 1. Symbols and Initial values

Symbol	Value	Description
$W(0)=\begin{bmatrix} w_{11}(0) & w_{12}(0) & w_{13}(0) \\ w_{21}(0) & w_{22}(0) & w_{23}(0) \\ w_{31}(0) & w_{32}(0) & w_{33}(0) \end{bmatrix}$ $b(0)$	$W(0)=\begin{bmatrix} -1.7502 & -0.8314 & -1.1564 \\ -0.2857 & -0.9792 & -0.5336 \\ -2.0026 & 0.9642 & 0.5201 \end{bmatrix}$ $b(0)=10^{-5}$	Weights in input and hidden layer
$u(0)$	$u(0)=0$	Control Signal
$\eta(k)$	$\eta(k)=0.01$	Learning Rate
t_s	$t_s=0.01$	Sampling Time

The system jacobian information is approximated using the following equation:

$$\frac{\partial y(k+1)}{\partial u(k)} = \begin{cases} 1 & , \ if \quad u(k)-u(k-1) \cong 0 \\ \dfrac{y(k+1)-y(k)}{u(k)-u(k-1)} & , \ otherwise \end{cases} \qquad \textbf{(2)}$$

Utilize tan-sigmoid function ($v(x) = \dfrac{e^{x}-e^{-x}}{e^{x}+e^{-x}}$) as activation functions in hidden layer.

(Hints: $\dfrac{\partial v(x)}{\partial x} = 1 - v^{2}(x)$)

a) Give the details related to the update rules for neural network controller parameters using chain rule so as to minimize the following objective function:

$$J(e_{tr}(k)) = \frac{1}{2} e_{tr}{}^{2}(k) \qquad \textbf{(3)}$$

where

$$e_{tr}(k) = r(k) - y(k)$$

b) Design (Write matlab m-file code) an adaptive NN controller using gradient descent in order to minimize the objective function in (3) for the given reference signal in fig 2. The initial values of weights in NN controller are initialized as in Table 1. You can download reference signal in dost system and upload using given m-file.

Plot

i) The alternation of the controller parameters versus time

ii) Reference-system signal versus time.

iii) Control Signal versus time.

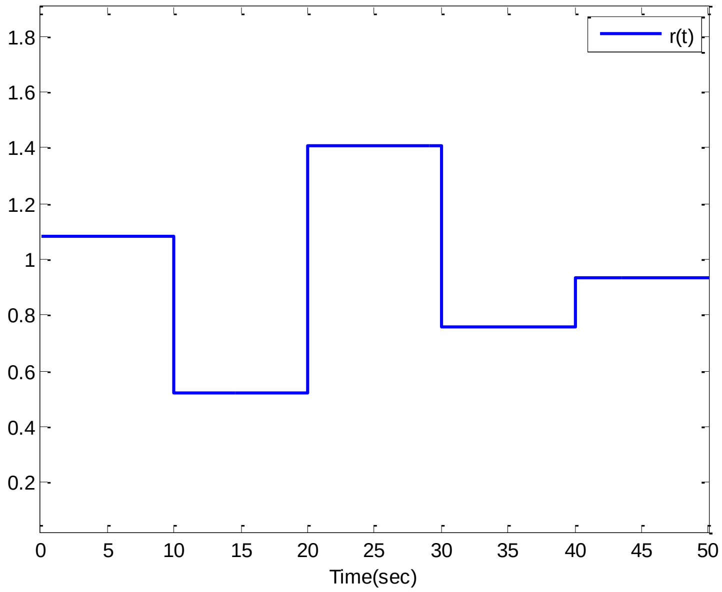

Fig.2 Reference Signal

PID Type Fuzzy Controller

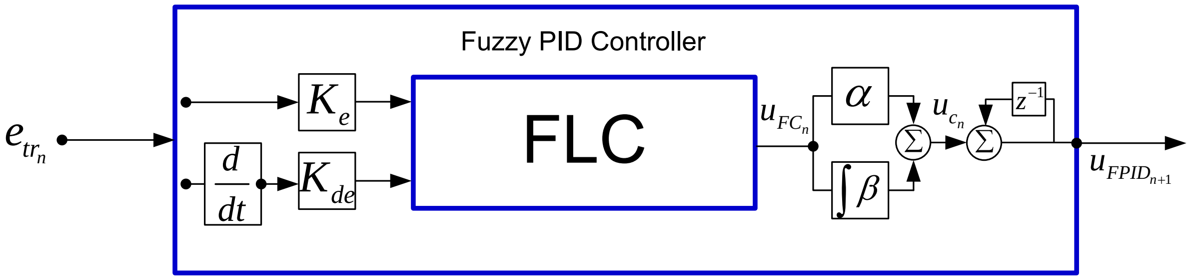

Fig.3 PID Type Fuzzy Controller(F PID C)

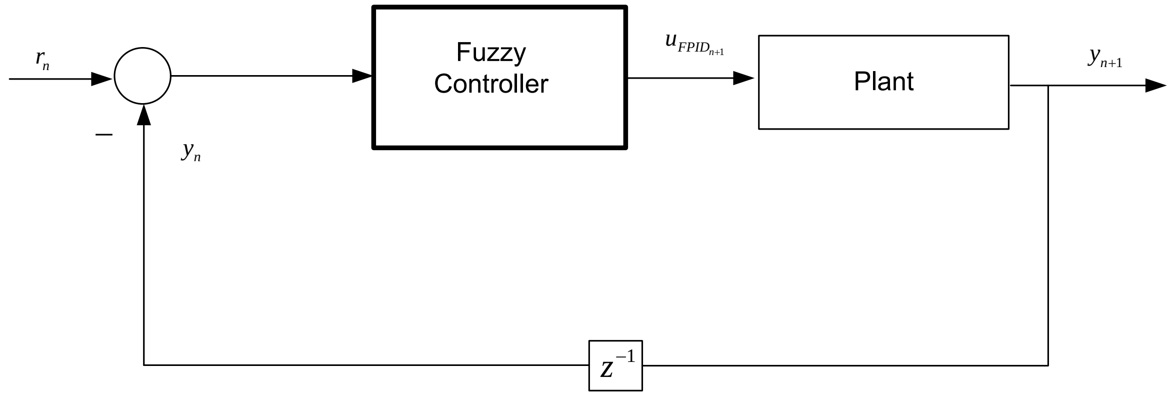

Fig.4 Fuzzy Control

In fig. 3-4, the PID type fuzzy controller is illustrated, where e_{tr_n} is the tracking error and $u_{FPID_{n+1}}$ is the control signal produced by fuzzy pid controller at time index *n*. In this assignment, triangular membership functions with {-1,-0.4,0,0.4,1} cores as in [2] are chosen for each linguistic value of the e and $\dot{e}$ as shown in fig. 5.

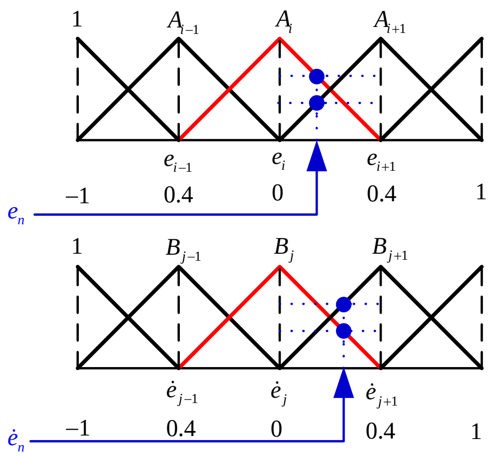

Fig.5 The Membership Functions of A_i and B_j

Center of gravity method has been utilized as defuzzification method. Inputs of the fuzzy controller are as follows:

$$e_n = K_{e_n} e_{tr_n} \quad , \quad \dot{e}_n = K_{de_n} \dot{e}_{tr_n} \qquad \textbf{(4)}$$

The PID type fuzzy controller produces a control signal as follows:

$$
\begin{aligned}
u_{FC_n} &= f(K_{e_n}, K_{de_n}, e_n, \dot{e}_n) \\
u_{c_n} &= \alpha_n\, u_{FC_n} + \beta_n [u_{FC_n} + u_{FC_{n-1}}] \\
u_{FPID_{n+1}} &= u_{FPID_n} + u_{c_n}
\end{aligned} \tag{5}
$$

where K_{e_n}, K_{de_n} are the input scaling coefficients and α_n and β_n are the output coefficient of the derivative and integral part of the pid type fuzzy controller respectively. The control signal produced by the derivative part is [2]

$$
\begin{aligned}
u_{FC_n} = {} & A_i(e_n)B_j(\dot{e}_n)u_{ij} + A_{i+1}(e_n)B_j(\dot{e}_n)u_{i+1\,j} \\
& A_i(e_n)B_{j+1}(\dot{e}_n)u_{ij+1} + A_{i+1}(e_n)B_{j+1}(\dot{e}_n)u_{i+1\,j+1}
\end{aligned} \tag{6}
$$

where

$$
A_i(e_n) = \frac{e_{i+1} - e_n}{e_{i+1} - e_i} \quad , \; A_{i+1}(e_n) = \frac{e_n - e_i}{e_{i+1} - e_i}
$$

$$
B_j(\dot{e}_n) = \frac{\dot{e}_{j+1} - \dot{e}_n}{\dot{e}_{j+1} - \dot{e}_j} \quad , \; B_{j+1}(\dot{e}_n) = \frac{\dot{e}_n - \dot{e}_j}{\dot{e}_{j+1} - \dot{e}_j}
$$

Fuzzy Control rules in table 2 are going to be utilized to control nonlinear CSTR system given in reference [4].

Table 2. Fuzzy Control Rules

	$\dot{e}_{-2}$	$\dot{e}_{-1}$	$\dot{e}_0$	$\dot{e}_1$	$\dot{e}_2$
e_{-2}	-1	-0.7	-0.5	-0.3	0
e_{-1}	-0.7	-0.4	-0.2	0	0.3
e_0	-0.5	-0.2	0	0.2	0.5
e_1	-0.3	0	0.2	0.4	0.7
e_2	0	0.3	0.5	0.7	1

a) Obtain the control procedure for the given problem step by step.
Ex:
Step 1: Calculate tracking error
Step 2: Obtain the inputs of the controller
….
….   Calculate firing….
Step X: Calculate the current control signal
Step X+1: Apply……….
…….

b) Design(Write matlab m-file code) a PID type fuzzy controller in order to minimize the tracking error for the given reference signal in fig 6.

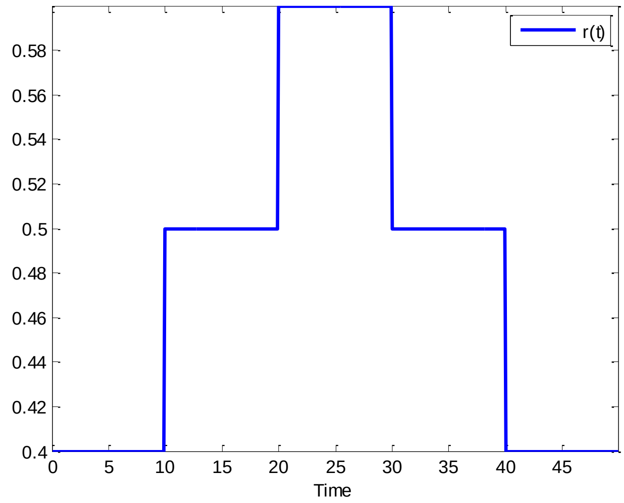

Fig.6 Reference Signal (If required, you can change the period of the reference signal)

c) Determine the scaling coeffients of the controller via Genetic algorithm use $J = \frac{1}{2}\sum_{n=1}^{\infty}[r_n - y_n]^2 + \frac{1}{2}\lambda\sum_{n=1}^{\infty}[u_n - u_{n-1}]^2$ as objective function to be minimized

i) For different values of λ (0.1, 0.5, 1, 10, 100) plot the output of the system and reference signal and control signal .

d) Propose any adaptation mechanism for this controller based on neural network or fuzzy logic or any other intelligent method. Ilustrate with figures and explain the working principle of the proposed mechanism.

Note: The fourth order Runge-Kutta method will be used for the simulation of CSTR system. Please find the Runge-Kutta MATLAB function for CSTR system on DOST.

Do not forget to submit a **report** with your **MATLAB files** related to the assignment.

Due date: 03/06/2022

We refer to the following references for detailed informations related to the **Neural network controller** and **PID Type Fuzzy Controller**.

1) Huailin Shu, Youguo Pi "**PID Neural Networks for time-delay systems**" Computers and Chemical Engineering 24(2000) , 859-862

2) Wu Zhi Qiao, Masaharu Mizumoto**" PID Type Fuzzy Controller and parameters adaptive method"**, Fuzzy Sets and Systems 78(1996) 23-35

3) Zhi-Wei Woo, Hung-Yuan Chung, Jin-Jye Lin,**" A PID Type fuzzy controller with self tuning scaling factors"**, Fuzzy Sets and Systems 115(2000) 321-326

4) W. Wu and Y.-S. Chou, "**Adaptive feedforward and feedback control of non-linear time-varying uncertain systems**," Int. J. Control, vol. 72, no. 12, pp. 1127–1138, Jan. 1999.