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Modified Fuzzy PID Controller Using CAN Network for Controlling DC Motor

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Abstract: The use of a data network in a control loop has gained increasing attentions in recent years due to its cost effective and flexible applications. One of the major challenges in Networked Control System (NCS) is the network-induced delay effect in the control loop. The aim of the proposed Modified Fuzzy PID Logic Controller scheme is to improve the performance of the networked DC motor controller and also to compare the results with Fuzzy and Zeigler-Nichols tuned Networked Proportional-Integral-Derivative Controller. The performance of the proposed network controller has been simulated using MATLAB/SIMULINK and verified with real time systems.

Key words: Networked Control Systems (NCS), Proportional-Integral-Derivative Controllers (PID), Fuzzy Logic Controller (FLC), Controller Area Network (CAN), DC motor

INTRODUCTION

Networked Control System is the adaptation of communication network for information exchange between controllers, sensors and actuators to realize a closed control loop. Networks reduce the complexity in wiring connections and the costs of Medias (Seiler and Sengupta, 2005; Nesic and Teel, 2004; Tabbara and Nesic, 2008). They are easy to maintain and also enable remote data transfer and data exchanges among users. Because of these benefits many industries and institutions has shown interest in applying different types of networks for their remote industrial control and automation.

Regardless of the types of networks, the overall performance of NCS is affected by two major challenges as networked induced delay and data losses (Hespanha *et al*., 2007). The challenges of networked DC motor are generally controlled by conventional proportional-integral-derivative controllers since, they are less expensive with inexpensive maintenance, designed easily and very effective (Sharmila and Devarajan, 2010; Lee, 1990a, b). But mathematical model of the controller and tuning of PID parameters are difficult and generally not used for non-linear systems. Hence to overcome these challenges auto-tuning and adaptive PID controller was developed with few mathematical calculations.

At first, a PID controller is designed with a practical motor model. The transfer function model of the motor is then used to design the digital PID controller. The fuzzy modeling is generated for self tuning of PID controllers. The earlier Fuzzy Logic Controller Model is modified and simulated using MATLAB® and Simulink® by adding the network delays of NCS. The above results were verified on CAN bus connected PIC microcontroller network.

MODELING

The CAN bus connects the three nodes namely Sensor node, Controller node and Reference node. Each node consists of a microcontroller and a CAN BUS interface controller (Fig. 1). Encoder pulse from speed sensor is used by Sensor node to calculate the speed of the motor and the information is transmitted to the controller node through CAN bus. The reference node gives the reference speed and the information is sent to controller node. The controller node calculates the duty ratio and generates the PWM signal which is given to DC to DC converter (Ren *et al*., 2009).

Fuzzy PID controller: A Proportional Integral Derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems-a PID is the most commonly used feedback controller (Ogata, 2002). A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

The PID controller calculation (algorithm) involves three separate constant parameters and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I and D. Heuristically, these values can be interpreted in terms of

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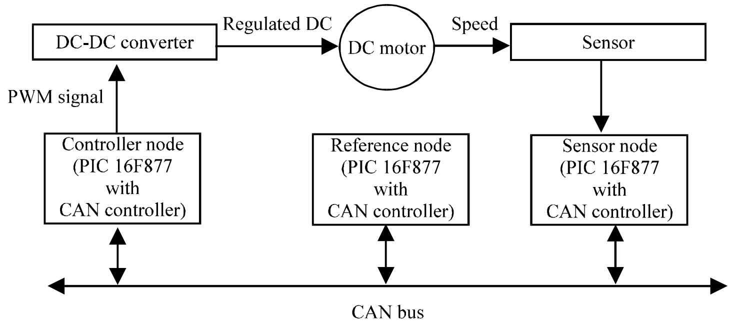

Fig. 1: An overall real-time networked control system

time: P depends on the present error, I on the accumulation of past errors and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supplied to a heating element.

In the absence of knowledge of the underlying process, a PID controller is the best controller. By tuning the three parameters in the PID Controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

Some applications may require using only one or two actions to provide the appropriate system control (Li and Tso, 2000; Tang *et al*., 2001; Luo and Chen, 2000). This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common since, derivative action is sensitive to measurement noise whereas the absence of an integral term may prevent the system from reaching its target value due to the control action. The basic structure of the PID controller is first described in the Eq. 1 and as well as in Fig. 2:

$$U_C(t)=K_P+K_I\int edt+K_D\frac{de(t)}{dt} \tag{1}$$

$$U_C(t)=K_P\left(1+\frac{1}{T_I}\int edt+T_D\frac{de(t)}{dt}\right) \tag{2}$$

In this study, two inputs-three outputs self tuning of a PID controller is used. The controller uses the error and change of error as inputs to the self tuning and the gains

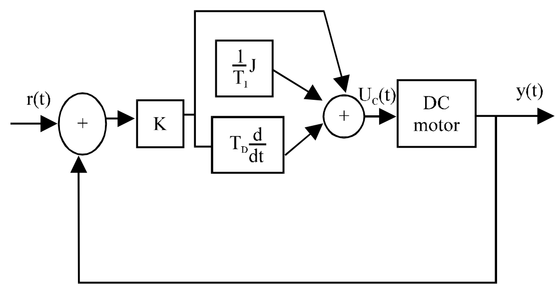

Fig. 2: PID control in closed loop

(K_{P1}, K_{I1} and K_{D1}) as outputs. The FLC is adding to the conventional PID controller to adjust the parameters of the PID controller on-line according to the change of the signals error and change of the error. The controller also contain a scaling gains inputs (K_e, $K_{\Delta e}$) as shown in Fig. 3 to satisfy the operational ranges (the universe of discourse) making them more general. Now the control action of the PID controller after self tuning can be describing as:

$$U_C(t)=K_{P2}+K_{I2}\int edt+K_{D2}\frac{de(t)}{dt} \tag{3}$$

where, K_{P2}, K_{I2} and K_{D2} are the new gains of PID controller and are equals to:

$$K_{P2}=K_{P1}\times K_P,\ K_{I2}=K_{I1}\times K_I,\ K_{D2}=K_{D1}\times K_D \tag{4}$$

Where:

K_{P1}, K_{I1} and K_{D1} = The gains outputs of fuzzy control, that are varying online with the output of the system under control

K_P, K_I and K_D = The initial values of the conventional PID controller

The general structure of fuzzy logic comprises of three principle components represented in Fig. 4.

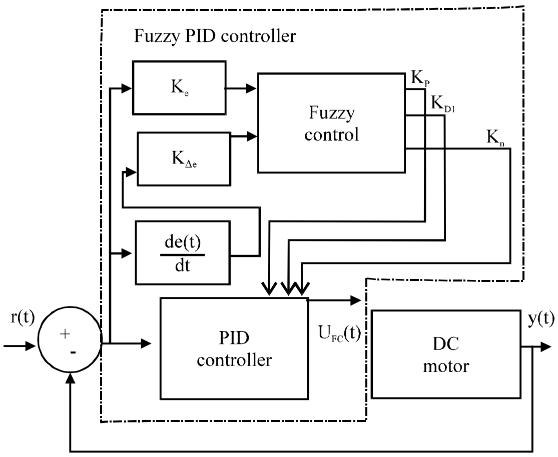

Fig. 3: Fuzzy self tuning

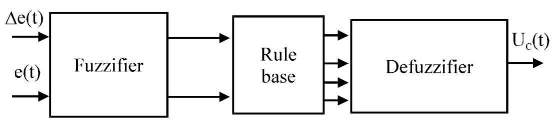

Fig. 4: Fuzzy general structure

Fuzzification: This converts input data into suitable linguistic values. As shown in Fig. 4, there are two inputs to the controller: error and rate change of the error signals. The error is defined as:

$$e(t) = r(t)-y(t) \quad (5)$$

Rate of error is defined as:

$$\Delta e(t) = \frac{de(t)}{dt} \quad (6)$$

Where:

r (t) = The reference input
y (t) = The output
e (t) = The error signal
Δe(t) = The rate of error

The seventh triangular input and output membership functions of the fuzzy self tuning are shown in the Fig. 5 and 6. For the system under study the universe of discourse for both e(t) and Δe(t) may be normalized from [-1,1] and the linguistic labels are {Negative Big, Negative, Medium, Negative Small, Zero, Positive Small, Positive Medium, Positive Big} and are referred to in the rules bases as {NB, NM, NS, ZE, PS, PM, PB} and the linguistic labels of the outputs are {Zero, Medium Small, Small, Medium, Big, Medium big, Very Big} and referred to in the rules bases as {Z, MS, S, M, B, MB, VB}.

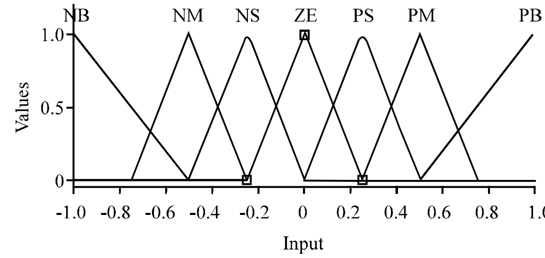

Fig. 5: Membership function of inputs

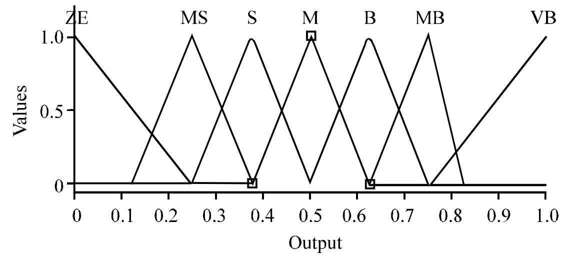

Fig. 6: Membership function of outputs

Table 1: Rule bases for determining the gain KP1

ė/e	NB	NS	ZE	PS	PB
NB	VB	VB	VB	VB	VB
NS	B	B	B	MB	MB
ZE	ZE	ZE	MS	S	S
PS	B	B	B	MB	VB
PB	VB	VB	VB	VB	VB

Table 2: Rule bases for determining the gain KI1

ė/e	NB	NS	ZE	PS	PB
NB	M	M	M	M	M
NS	S	S	S	S	S
ZE	MS	MS	ZE	MS	MS
PS	S	S	S	S	S
PB	M	M	M	M	M

Table 3: Rule bases for determining the gain KD1

ė/e	NB	NS	ZE	PS	PB
NB	ZE	S	M	MB	VB
NS	S	B	MB	VB	VB
ZE	M	MB	MB	VB	VB
PS	B	VB	VB	VB	VB
PB	VB	VB	VB	VB	VB

Rule base: A decision making logic which is simulating a human decision process inters fuzzy control action from the knowledge of the control rules and linguistic variable definitions. Table 1-3 show the control rules that used for fuzzy self tuning of PID controller.

Defuzzification: This yields a non fuzzy control action from inferred fuzzy control action. The most popular method, center of gravity or center of area is used for defuzzification. Where $u(u_j)$ member ship grad of the element u_j, u(nT) is the fuzzy control output, n is the number of discrete values on the universe of discourse:

$$u(nT) = \frac{\sum_{j=1}^{n} u(u_j) u_j}{\sum_{j=1}^{n} u(u_j)} \quad (7)$$

MODIFIED FUZZY CONTROLLER FOR NCS

The structure of FLC for a single input single output plant in a network is shown in Fig. 7. In Fig. 7, the control signal and plant output are transmitted through the network. Due to the use of the network, the control signal and feedback signal (plant output) inevitably contain the network induced delay and losses of data. In Fig. 7, r(t) is the reference input, y(t) is the plant output, e(t) is the error signal between the reference input and plant output and $U_C(t)$ is the control signal.

The modified fuzzy PID controller for the networked control dc motor is shown in the Fig. 8. The model is based on modulating the control signal $U_C(t)$ provided by the fuzzy PID controller with a single parameter K. The fuzzy modulator receives the input as the error signal e(t) which is the difference between the reference signal and the plant output signal y(t) in addition to the output from the fuzzy PID controller $U_C(t)$. The fuzzy modulator produces an output as modulation parameter K which is used to compensate the affects of the network induced time delay and data losses. The control signal produced by the fuzzy modulated networked PID controller is:

$$U_F(t) = K.U_C(t) \quad (8)$$

Two fuzzy linguistic variables, i.e., small and large are defined. The coefficients of the membership functions

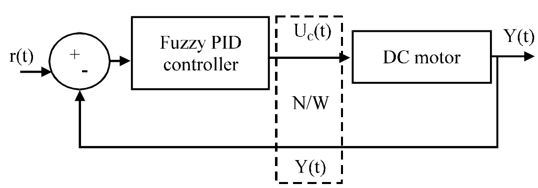

Fig. 7: Fuzzy logic controller for NCS

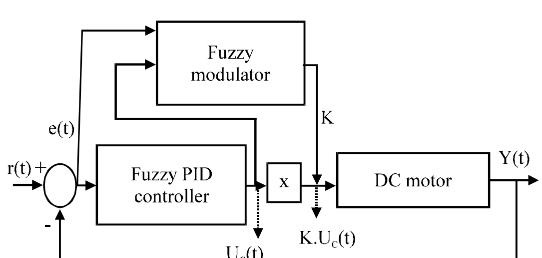

Fig. 8: Modified fuzzy logic controller for NCS

are determined by several trial and error methods with the plant and without the network. The fuzzy logic modulator used in this study is composed of the following rules:

- If e(t) is small and $U_{PID}(t)$ is small then K is K_1
- If e(t) is large and $U_{PID}(t)$ is large then K is K_2

Such that β<β1<β2<1 where K_i, i = 1, 2 are the consequent parameters corresponding to the modification parameter K.

SIMULATION RESULTS AND EXPERIMENTAL SETUP

In Fig. 9, the simulation scenario, the direct structure of the networked DC motor control system is simulated using MATLAB/SIMULINK under fully controlled environments for Fuzzy Logic controller, PID controller and Modified Fuzzy PID controller. The motor is controlled by the fuzzy logic controller with the insertions of network delays calculated for the CAN bus. The delays are varied according to different effects of interests. The disturbance and loss of input signal, control signal and the feedback signal were made for few milliseconds at each stage and the results were studied.

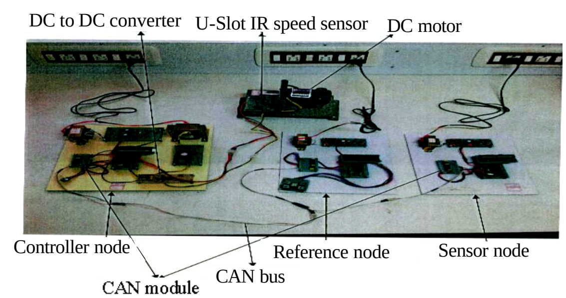

Fig. 9: Experimental setup

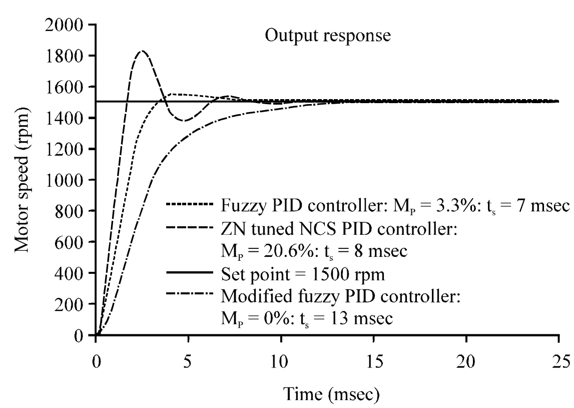

Fig. 10: Simulation output

Then, the results of the FLC are compared with the Zeigler-Nichols tuned PID controller and Fuzzy Modulated PID controller. Output responses of the system are obtained for all controllers used in this study. Figure 10 shows the comparison of the system performance for all controllers without data losses.

Experimental verification for the above modulated fuzzy PID controller in NCS (Fig. 10) has been performed to validate the simulation results. The DC motor is controlled digitally using PIC microcontrollers (PIC16F877) and CAN BUS interface controllers.

CONCLUSION

Networks and their applications play a promising role for real-time high performance networked control in industrial applications. This study presents Modified Fuzzy PID controller for CAN based networked control of DC motor. Simulations as well as experimental results are given to validate the algorithm. This presented model greatly improves the settling time and maximum peak overshoot. The analysis on using intelligent controls improves and strengthens the networked control systems concepts in the future.

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