

Designing and Fabricating Fuzzy Controller of DC Servo Motor with HMI

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Abstract – In this paper, the design and fabrication of fuzzy controller to DC servo motor for education is investigated. This equipment provides the basic experiment device for elementary control and automation courses in electronic and computer engineering, mechanical engineering. Student can understand the basic principles of Fuzzy control and its influence on system performance, master the method to adjust the speed controller parameters of the DC servo motor and comprehend the influence of disturbing torque on speed control performance, so as to learn the practical skills of the motion control. In addition, this equipment allows users to integrate the self-developed controller or third party controllers flexibly.

Keywords – Fuzzy logic, fuzzy controller, DC motor, servo motor.

I. INTRODUCTION

Nowaday, DC motor is widely used in industrial application, defense, robotics, home appliances etc. Therefore, speed and position control of motor is very important and required. The non-linear characteristic of DC motor could degrade the performance of the conventional controller. To reduce these effects, many advanced model control methods have been proposed by scientists such as analog PID controllers, digital PID controller [1], optimal controller [2], LQG... However, the performance of these methods depends on the accuracy of model and parameter of DC motor. Generally, it is difficult to find and accurate nonlinear model and indentify all parameters. The Fuzzy logic control (FLC) able to cope with system uncertainties.

The field of Fuzzy logic control has been making rapid progress in recent years. It is one of the most successful application of Fuzzy set theory introduced by L.A.Zadel [3] and applied in an attempt to control the systems that are difficult to model. Just as fuzzy logic can be described simply as computing with words rather than numbers; FLC can be described simply as control with sentences rather than equations. FLC can include empirical rules, especially useful in operator controlled plants. Tuning FLC may seem at first to be a daunting task. There are many parameters that can be adjusted. These include the rules, membership functions and any other gains within the control system.[4].

This paper present speed control system simulation blocks, especially that related with a separately excited D.C motor considerations, which can be applied as a experiental model for training in department of Mechatronic at Universities.

II. DC MOTOR MODEL

DC motor directly provides rotary motion and, coupled with wheels or drums and cables, can provide translational motion. The electric equivalent circuit of the armature and the free-body diagram of the rotor are shown in the figure 1

We will assume that the magnetic field is constant and, therefore, that the motor will generate a torque proportional to only the armature current I_a (input current) by a constant factor K_T as shown in the equation below

$$T_g = K_T \cdot I_a \tag{1}$$

Where K_T is the torque constant.

The back emf, E_g , is determined by the angular velocity of the shaft with a constant factor K_E

$$E_g = K_E \cdot \omega \tag{2}$$

Where ω is angular velocity of the shaft.

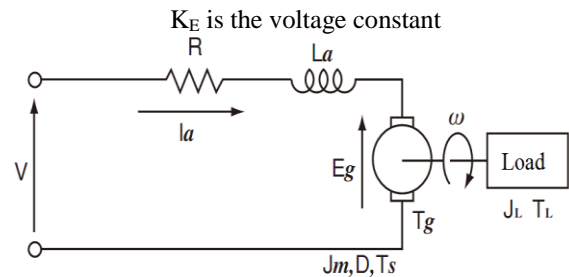


Figure 1. Equivalent circuit of DC motor

Apply Newton's 2nd law and Kirchhoff's voltage law to derive the following governing equations based on

$$V = E_g + R \cdot I_a + L_a \cdot \frac{dI_a}{dt} \tag{3}$$

$$V = K_E \cdot \omega + R \cdot I_a + L_a \cdot \frac{dI_a}{dt} \tag{4}$$

Because L_a is very small so we ignore this component, the equation (3) and (4) become:

$$V - R \cdot I_a = K_E \cdot \omega \tag{5}$$

$$\omega = \frac{V - R \cdot I_a}{K_E} \tag{6}$$

Equation of load torque T_m :

$$T_m = (J_m + J_L) \cdot \frac{d\omega}{dt} + D \cdot \omega + T_f + T_L \quad (7)$$

Where

J_m : Motor moment of inertia.

J_L : Load moment of inertia converted on a motor shaft

D : Motor damping coefficient

T_f : Motor friction torque

T_L : Load friction torque converted on a motor shaft

From torque equation

$$T_m = T_g = K_T I_a \quad (8)$$

Assume $J = J_m + J_L$, $T_f + T_L = 0$, $D = 0$.

Apply Laplace transform:

$$V(s) = \frac{1}{K_T} s \cdot J \cdot (s \cdot L_a + R) \cdot \omega(s) + K_E \cdot \omega(s) \quad (9)$$

$$G(s) = \frac{\omega(s)}{V(s)} = \frac{K_T}{s \cdot J \cdot (s \cdot L_a + R) + K_E \cdot K_T} \quad (10)$$

According to DC motor datasheet $L_a \ll \frac{R^2 J}{K_E K_T}$ [5],

equation (10) expressed

$$G_m(s) = \frac{\omega(s)}{V(s)} = \frac{1/K_E}{(s \cdot \frac{R \cdot J}{K_E \cdot K_T} + 1)(s \cdot \frac{L_a}{R} + 1)} \quad (11)$$

Set

$$T_m = \frac{R \cdot J}{K_E \cdot K_T} \quad (12)$$

T_m is the mechanical time constant - second

$$T_e = \frac{L_a}{R} \quad (13)$$

T_e is the electrical time constant - second

$$G_m(s) = \frac{\omega(s)}{V(s)} = \frac{1/K_E}{(s \cdot T_m + 1)(s \cdot T_e + 1)} \quad (14)$$

If $T_m \gg T_e$ transfer function expressed

$$G_m(s) = \frac{\omega(s)}{V(s)} = \frac{1/K_E}{(s \cdot T_m + 1)}$$

DC motor is selected in this research: DC SERVOMOTOR ENCODER – TS1982 by manufacturer TAMAGAWA SEIKI [5]

TABLE 1: SPECIFICATION OF DC MOTOR TS1982

Winding no	E6
Torque constant (KT)	5.7 10-2 N.m/A
Voltage constant (KE)	6.0 10-3 V/(min-1)
Amature resistance (Ra)	1.1 Ω
Amature inductance (La)	0.9 mH
Rated output power	60 W
Rated voltage (Vo)	25V
Rated current (Io)	3.9 A
Rated speed (No)	3000 min-1
Rated torque (To)	0.191 Nm
Momen of inertial (JM)	0.157x10-4 kg.m2
Mechanical time constant (Tm)	5.3 m sec
Electrical time constant (Te)	0.82 m.sec
Thermal resistance (Rth)	2.3oC/W
Friction torque (Tf)	1.7x10-2 N.m
Mass	0.65 kg

III. DESIGN CONTROLLER

The fuzzy controller is designed for training and research of students specialized in mechatronics and automation so the model has the following functions:

Measure and test motor speed: this module is used for motor model identification. Most of our students often use the second hand servo motors, which they difficult find all specification of motor to build mathematical models for control. At that time, students need to conduct model identification. With this function, students can test the performance, measure the speed of any servo motor that satisfies some of the controller specifications (operating voltage and maximum current). Based on the measured results, students can identify the model quite accurately. This function is very useful in model identification. Especially in trajectory control in robot application, synchronize velocity of motor. This module will assist students participating in the robotic competition at Danang College of Technology.

Simulation of Fuzzy logic control: the theory of fuzzy control is often difficult to explain to undergrade students. So this function has bult to help them deeply understand theory of FLC. It can simulate how the fuzzy controller work and students can understand how the fuzzy controller change the output signal when the input signal changed.

Because this function serves to explain in lectures, the program only builds SISO (Single Input Single Output).

Hardware experiment modul: this is a complete test with full functionality such as fuzzification, fuzzy rule base, defuzzification of the fuzzy controller and connected to the actual devices. On the Human Machine Interface, students can set the parameters of the fuzzy controller to monitor the change of motor speed as well as time response.

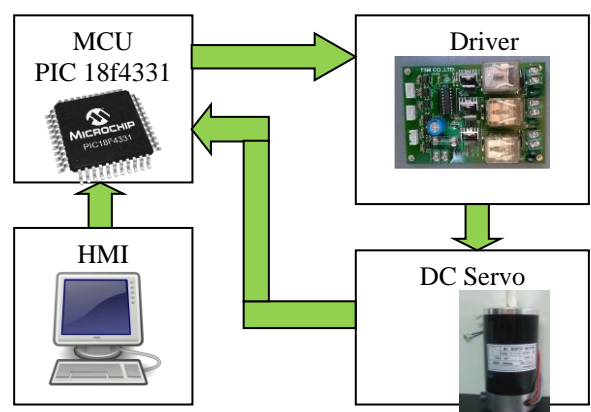


Figure 2. Block diagram of the Fuzzy controller

A. MICROCONTROLLER

This module is main controller, it will receive signal from computer via serial port (RS232) to control the speed of motor by change the PWM value. Encoder equipped on the DC motor will send signal to this microcontroller and count number of pulse. The speed of motor continuous update and transmit to computer to graph on the HMI.

Currently, many PIC microcontroller series are commercialized and they have different functions for specific applications. PIC18f4x31 is among the microcontroller refer to DC motor control, it is widely used in industrial application. Therefore, we select this microcontroller PIC 18f4331 for this study.

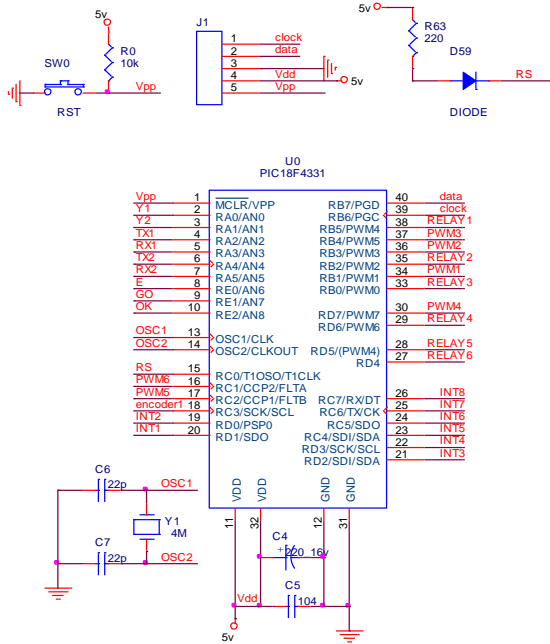


Figure 3. Diagram of microcontroller

We use serial port DB9 to transmit data between computer and microcontroller. Because there is difference voltage between computer and microcontroller so we must use IC MAX232 to adapt the logic level (figure 4)

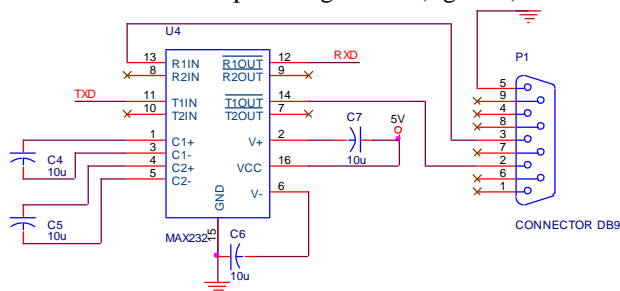


Figure 4. Serial communication module

B. DESIGN MODULE OF DRIVER

To increase stability of whole control module, we need to use opto modle for separate power between microcontroller and motor. The driver modul designed by using Metal-Oxide Semiconductor Field-Effect Transistor MOSFET IRF540 which able to stand up to 5A and controlled by change voltage on pin Gate. The PUSH PULL output stage circuit used for triggng.

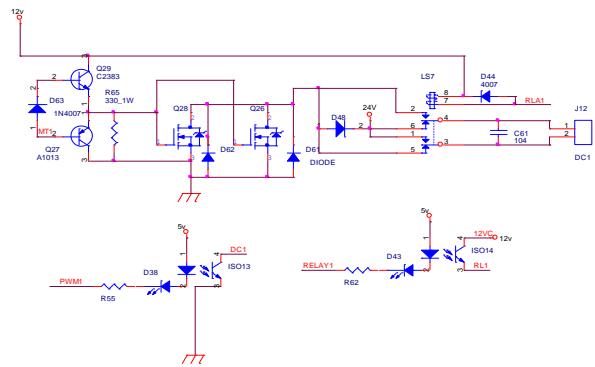


Figure 5. DC motor driver circuit

C. DESIGN FUZZY LOGIC CONTROLLER

Fuzzy logic controller is shown on figure 6, this controller is composed of:

- Fuzzification interface
- Defuzzification interface
- Rule base
- Decision making unit (inference mechanism)

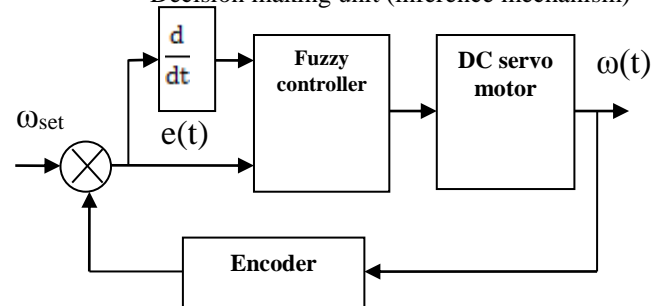


Figure 6. Block diagram of the Fuzzy controller

Inputs of controller are the error $e(t)$ between the reference (ω_{set}) and actual speed (ω) and the change in error \dot{e} , the output is the change in amature voltage as PWM to control motor speed. The range of input and output signals are normalized into $[-1,1]$.

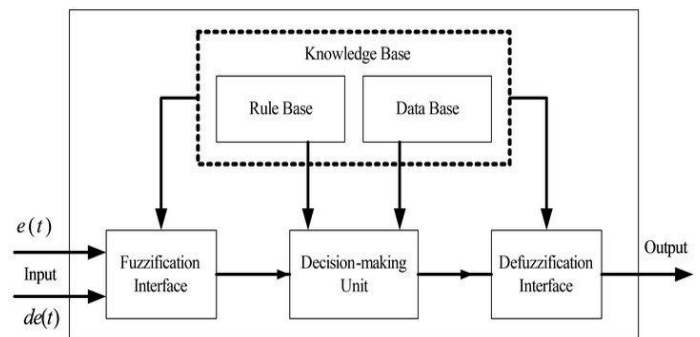


Figure 7. Block diagram of fuzzy controller [6]

To perform fuzzy computation, the input and output must be converted from numerical or “crisp” value to linguistic form. The term of “Small” and “Large” are used to quantize the inputs and outputs to linguistic value. In this paper, linguistic terms that used to represent inputs and outputs value are defined by five fuzzy variables

VS – Very Small
 SM – Small
 ZR – Zero
 LR – Large
 VL – Very Large

And the triangular function is selected for fuzzy membership. Value of a and b in membership function can be adjusted by user.

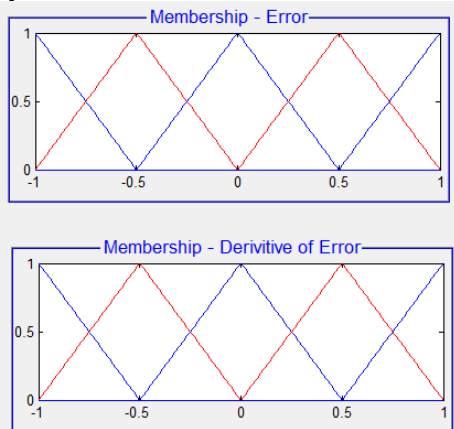


Figure 8. Define membership of inputs

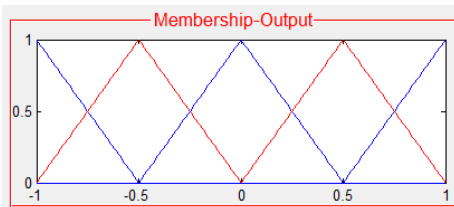


Figure 9. Define membership of output

Define the fuzzy rules.

The fuzzy rules are merely a series of if-then statements as mentioned above. These statements are derived by an expert to achieve optimum results.

Some examples of these rules are:

- i) If angle is zero and angular velocity is zero then speed is also zero.
 - ii) If angle is zero and angular velocity is low then the speed shall be low.
- R1: if the error $e(t) = VS$ and the change in error $\frac{de(t)}{dt} = VS$
 then PWM = VS
- R2: if the error $e(t) = VS$ and the change in error $\frac{de(t)}{dt} = SM$
 then PWM = VS
- R3: if the error $e(t) = VS$ and the change in error $\frac{de(t)}{dt} = ZR$
 then PWM = SM
- R4: if the error $e(t) = VS$ and the change in error $\frac{de(t)}{dt} = LR$
 then PWM = SM
- R5: if the error $e(t) = VS$ and the change in error $\frac{de(t)}{dt} = VL$
 then PWM = ZR

- R6: if the error $e(t) = S$ and the change in error $\frac{de(t)}{dt} = VS$
 then PWM = VS
- R7: if the error $e(t) = S$ and the change in error $\frac{de(t)}{dt} = SM$
 then PWM = SM
- R8: if the error $e(t) = S$ and the change in error $\frac{de(t)}{dt} = ZR$
 then PWM = SM
- R9: if the error $e(t) = S$ and the change in error $\frac{de(t)}{dt} = LR$
 then PWM = ZR
- R10: if the error $e(t) = S$ and the change in error $\frac{de(t)}{dt} = VL$
 then PWM = LR
- R11: if the error $e(t) = ZR$ and the change in error $\frac{de(t)}{dt} = VS$
 then PWM = SM
- R12: if the error $e(t) = ZR$ and the change in error $\frac{de(t)}{dt} = SM$
 then PWM = SM
- R13: if the error $e(t) = ZR$ and the change in error $\frac{de(t)}{dt} = ZR$
 then PWM = ZR
- R14: if the error $e(t) = ZR$ and the change in error $\frac{de(t)}{dt} = LR$
 then PWM = LR
- R15: if the error $e(t) = ZR$ and the change in error $\frac{de(t)}{dt} = VL$
 then PWM = LR
- R16: if the error $e(t) = LR$ and the change in error $\frac{de(t)}{dt} = VS$
 then PWM = SM
- R17: if the error $e(t) = LR$ and the change in error $\frac{de(t)}{dt} = SM$
 then PWM = ZR
- R18: if the error $e(t) = LR$ and the change in error $\frac{de(t)}{dt} = ZR$
 then PWM = LR
- R19: if the error $e(t) = LR$ and the change in error $\frac{de(t)}{dt} = LR$
 then PWM = LR
- R20: if the error $e(t) = LR$ and the change in error $\frac{de(t)}{dt} = VL$
 then PWM = VL
- R21: if the error $e(t) = VL$ and the change in error $\frac{de(t)}{dt} = VS$
 then PWM = ZR
- R22: if the error $e(t) = VL$ and the change in error $\frac{de(t)}{dt} = SM$
 then PWM = LR
- R23: if the error $e(t) = VL$ and the change in error $\frac{de(t)}{dt} = ZR$
 then PWM = LR
- R24: if the error $e(t) = VL$ and the change in error $\frac{de(t)}{dt} = LR$
 then PWM = VL

R25:if the error $s \dot{e}(t) = VL$ and the change in error $\frac{de(t)}{dt} = VL$ then PWM = VL.

Defuzzification

Here are MAX – MIN type decomposition is used. In order to choose an appropriate representative value as the final output (crisp values), defuzzification must be done. There are numerous defuzzification methods, but the most common one used is the center of gravity of the set as shown below.

$$Z^* = \frac{\int \mu(z).z.dz}{\int \mu(z).dz} \quad (15)$$

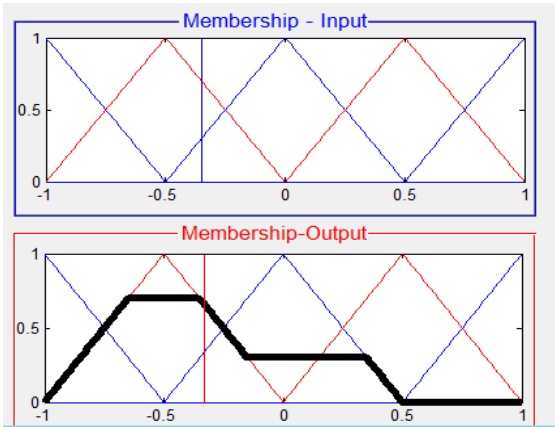


Figure 10. Result of defuzzification process if speed error $e(t) = -0.3$. Test the SISO module

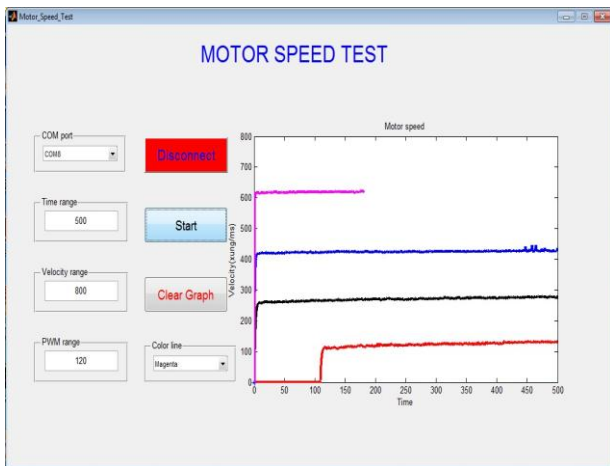


Figure 11. HMI of speed measurement module

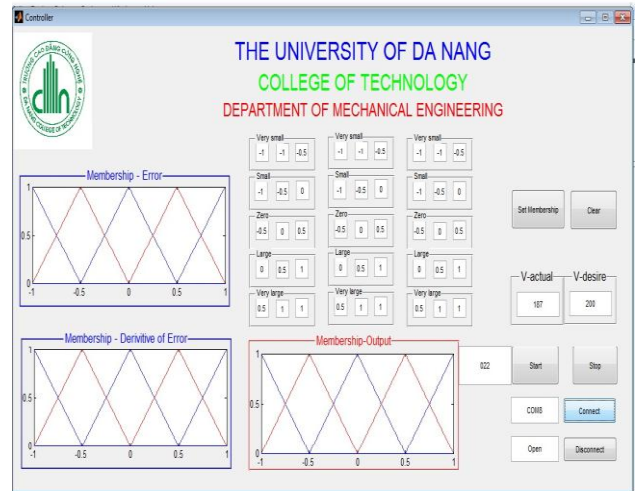


Figure 12. HMI of Fuzzy controller



Figure 13. Experimental modul test

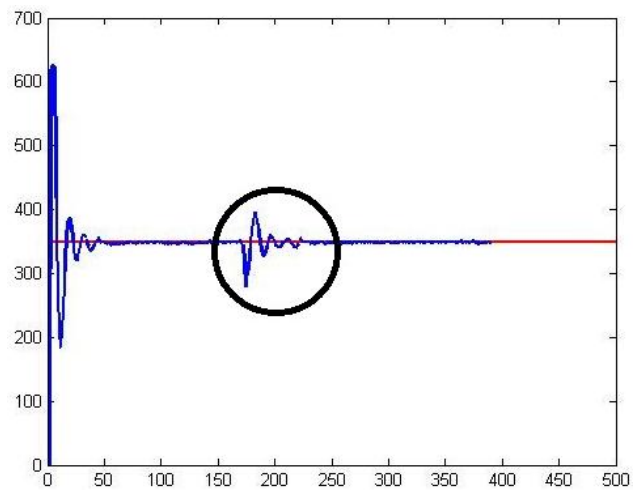


Figure 14. Response of controller under disturbance by adding load

IV. CONCLUSION

This study has demonstrated the implementation of Fuzzy Logic control for the speed control of DC motor by using microcontroller. The controller shows very good result by tracking the setting velocity under load and no load condition. The experimental modul is useful for training in Department of Mechatronic, Danang College of Technology.

REFERENCES

- [1] P. Ravi Kumar, V. Naga Babu, "Position control of Servo systems using PID controller turning with soft computing optimization technique", International Journal of Engineering Research and Technology, Vol 3, Issue 11, 2014.
- [2] Tayfun Abut, "Modeling and Optimal control of a DC motor", International journal of Engineering Trends and Technology, Vol 32, No. 3, 2016
- [3] L. A. Zadeh, "Fuzzy sets", Information and Control 8, Page 338 – 353, 1965
- [4] Pavol Fedor, Daniela Perdukova, "Simple fuzzy controller structure", Acta Electrotechnica At Informatica No.4, Vol.5, 2005.
- [5] DC servomotors and DC motor Calalogue No.2, T12, Tamagawa Seiki Co., Ltd.
- [6] Website <http://championed.info>.