Optimized Fuzzy Logic for Motion Control

Radhesham Gayakwad

Dept. of PG Studies and Research in Applied Electronics, Gulbarga University, Gulbarga, Karnataka, India, E-mail: radheshamgg@gmail.com

Abstract: For any fuzzy logic application the first and foremost task is to select the optimum number and shape of membership functions such as bell shape, singleton, triangular, etc. for fuzzification; then it is equally essential to select the appropriate defuzzification method, such as COG, COM, MOM, etc. The sampling rate to execute the given command is another important parameter. If these three parameters are optimally selected then the output response of motion controller will have a shorter rise time, less settling time, minimized overshoots/undershoots and negligible steady state error. Hence, the systematic study on selection of number and shape of membership function, selection of defuzzification methods and sampling time for speed control of PMDC micro motor is studied experimentally by applying LabVIEW software. The experimental results reveal that 7 numbers of triangular membership functions, COG defuzzification method and 1 millisecond (msec) sampling rate for labVIEW program execution are the optimum parameters for motion control.

Keywords: fuzzy logic; pmdc motor; labVIEW

1 Introduction

Conventional controllers such as microprocessors or microcontrollers are suitable for parameter measurements such as pressure, temperature, liquid flow, displacement motor speed, etc. Such controllers are reliable only when the measuring parameters are linear and time invariant and when the mathematical model of these parameters are available, because conventional controllers work only on mathematical models of the parameters. If the system is complex and the associated parameters are ill-defined, imprecise, or time variant, then the mathematical models of such complex parameters are difficult to formulate, and hence conventional controllers fail to control such systems effectively. The Fuzzy Logic Controller (FLC) is a controller which can control the said systems and associated parameters because the design and development of FLC is relatively very easy and less time consuming, and it is robust, flexible and adaptive. To control the processing parameters, the designers need not be experts on the system or sub-system. The most important feature of FLC is that the mathematical model of the controlling parameters is not required at all. Moreover, the parameters can be described by linguistic variables (like warm, fast, medium, etc.) which can be controlled using simple IF-THEN rules.

Li Zhang proposed a fuzzy controller with easier and faster-tuning techniques. He reported a practical computer-aided tuning technique for fuzzy control. He employed triangular membership functions for fuzzification and centre of gravity (COG) for defuzzification. [1-2]. Xie kanglin and Fu Jin Yu reported the determination of membership functions and fuzzy rules of a neural network FLC system. The problem of how to find the most optimal fuzzy rules and input/output membership functions in developing a fuzzy control system and a study of neural networks has been presented in [3]. Castro reported on how many rules are necessary to get a good fuzzy controller. He used triangular membership functions and weighted sum of centroid defuzzification method [4]. An overview of the general class of parameterized defuzzification methods were employed by Filev and Yager [5-6]. Yager and Filev also reported a simple adaptive defuzzification method and a discussion on the issue of defuzzification methods and the selection of fuzzy sets [7-8]. An interesting strategy for dealing with the defuzzification problem based on sensitivity analysis was developed by Mabuchi [9].

The survey of available literature survey shows that so far there is no report of an experimental study of PMDC micro-motor speed characteristics by applying various numbers of triangular membership functions and different types of defuzzification methods and critical aspect of sampling time of FLC and associated with LabVIEW program. Hence we have studied this case.

2 Experimental Set-up

The block diagram for the speed control of PMDC micro motor (Model: 2230 U015S; rating: 15V, 7 mA and 8400 rpm) is shown in Fig. 1.

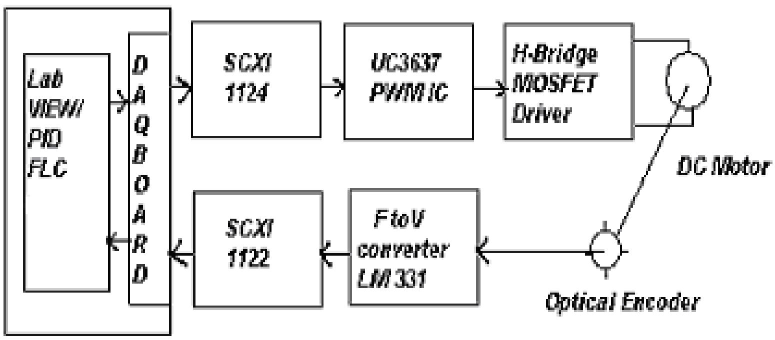

Figure 1

Diagram for speed control of PMDC micro-motor

The PWM signal generated by UC3637 Switched Mode PWM controller chip is fed to the H-bridge MOSFET driver circuit, which in turn drives the motor. The optical encoder attached to the shaft of the motor generates the TTL pulses; these pulses are converted into analog voltage using LM331 F/V converter IC. This analog voltage is fed to the PC through SCXI1122 card. After the execution of the velocity command through LabVIEW*6i*, the analog output voltage is available through DAQ (Data acquisition) board at 1124 card, which is given as input command to the UC3637, where the complete closed loop feedback control is established between the PC and the motor driving circuit.

3 Fuzzy Logic Controller (FLC)

A general FLC consists of four modules; a fuzzification module, a fuzzy rule base, a fuzzy inference engine and a defuzzification module. The interconnections of these modules are shown Figure 2. A fuzzy controller operates by repeating a cycle involving the following steps:

a) Measurements are taken of all variables that represent the relevant conditions of the controlling process.

b) These measurements, which are in crisp form (analog voltage or current), are converted into appropriate fuzzy sets to express measurement uncertainties. This is called fuzzification.

c) These fuzzified measurements are then used by the decision-making logic to evaluate the control rules stored in the fuzzy knowledge base. The result of this evaluation is a fuzzy set, defined by the universe of possible action.

d) This fuzzy set is then converted into a single crisp value (i.e. analog voltage or current), which in some sense is the best representative of the fuzzy set. This conversion is called defuzzification. The defuzzified value represents the final action taken by the fuzzy controller.

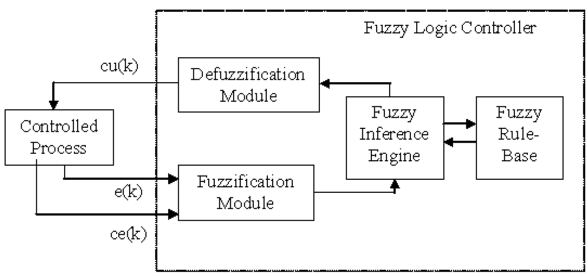

Figure 2
Basic block diagram of fuzzy logic controller

3.1 Membership Functions

Membership functions characterize the fuzziness in a fuzzy set, whether the elements in the set are discrete or continuous in a graphical form for eventual use in the mathematical formalism of fuzzy set theory [10]. The rules used to describe fuzziness graphically are also fuzzy. Since all the information contained in a fuzzy set is described by its membership functions, it is useful to develop a lexicon of terms to describe various special featured functions, such as low temperature, high speed, medium pressure, etc. There are several ways to graphically depict the membership functions that describe fuzziness. The most popular choices of the curves/shapes of the membership functions include: triangular, S, Z, bell-shape and singleton. The important character of these curves/shapes for purpose of use in fuzzy operation is the fact that they overlap. The precise shapes of these curves are not so important in the utility. Rather, it is the number of curves (partitions) used and their overlapping regions that are the most important ideas. Fig. 3 shows the lexicon of terms to describe speed characteristics of PMDC micro-motor for the speed range from 1000 rpm to 3000 rpm.

3.2 Defuzzification

Defuzzification is the conversion of a fuzzy quantity into a precise or crisp (like voltage or current) quantity. In the present work, three types of defuzzification methods are used:

a) Mean of Maxima (MOM) Method

In this method, defuzzification is made of the average of the two selected values.

b) Centre of Maxima COM) method

This method uses the overall output or union of all individual output fuzzy sets.

c) Centre of Gravity (COG) Method

This method uses the algebraic integrated value of the fuzzy sets, and it is most prevalent and physically appealing of all the defuzzification methods. In the present work, the COG defuzzification method is used.

3.3 Sampling Rate

In digital control systems, the sampling rate is the number of times per second a controller reads in sensor data and produces a new output value. The slower the sampling rate, the less responsive the system is, because the controller would always be working with that old data that were present when the last sample was taken. Hence, in the present work we have used three different sampling rates, i.e. 1 sec, 0.1 sec and 1 msec to check the response of speed of a DC motor. These three sampling rates were formulated and studied using LabVIEW software.

4 Description of the VI Diagram

As shown in Fig. 3, the input voltage from F/V through SCXI 1122 is accessed by analog input (Ai) channel. This analog voltage is converted into the corresponding speed using adders and multipliers. First DBL (double precision floating point) represents the set value of 3000 rpm. The error and change in error are found using two subtractors. These two signals are fed to the FLC. The FLC gives the control voltage through analog output (Ao) channel. The motor rpm is then controlled through UC3637 IC and H-Bridge MOSFET driver circuit. The measured speed status is displayed on the waveform chart monitor. All these events are carried out in a feedback loop (labelled as while-loop).

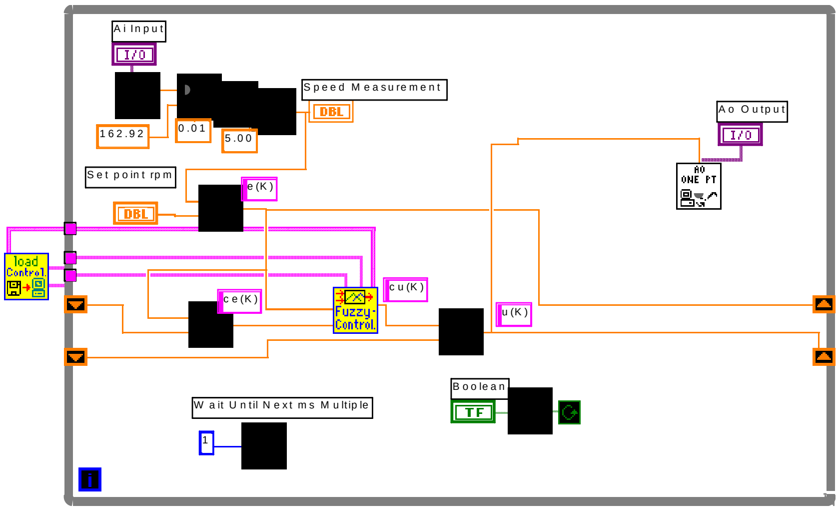

Figure 3

VI Diagram for speed control of PMDC Micro motor

5 Experimental Results

Here the effect of various numbered triangular membership functions, defuzzification methods and different sampling rates related to speed control of PMDC micro-motor are discussed.

5.1 Effect of Membership Functions

The FLC has been successfully implemented for the real time speed control of a PMDC micro-motor at 3000 rpm. First, 3-number triangular membership functions are chosen and the transient response is obtained. Similarly 5 and 7-number triangular membership functions are applied and their transient responses are observed. The experimental transients of these three functions are shown in Fig. 4. It is observed that for the 3-number triangular membership function, the settling time is 3.5 sec and steady state error is ±40 rpm. For the 5-number triangular membership function, a settling time of 2.7 sec and a steady state error of ±25 rpm oscillations are observed. The response of the 7-number triangular membership function exhibited no overshoots and undershoots and shorter settling time of 1.8 sec was obtained.

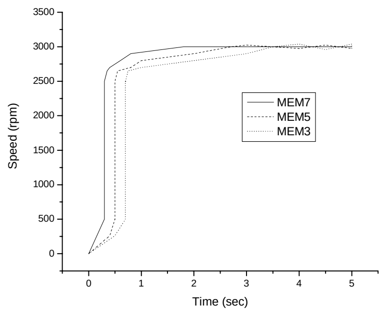

Figure 4

Experimental transient response for 3, 5, and 7-number triangular membership functions [MEM7= 7 number triangular membership functions, etc]

5.2 Effect of Defuzzification Methods

The three defuzzifications, i.e. COM, MOM and COG, are implemented and their effect on the transient response of PMDC micro-motor at 3000 rpm observed. The experimental results (Fig. 5) show that: for the MOM defuzzification method, the settling time is 2.8 sec with overshoots and undershoots of ±25 rpm; the COM defuzzification method has the settling time of 2.5 sec with steady state error of ±10 rpm; and in the case of the COG defuzzification method, the settling time is 2.0 sec without overshoots and undershoots and zero steady state error.

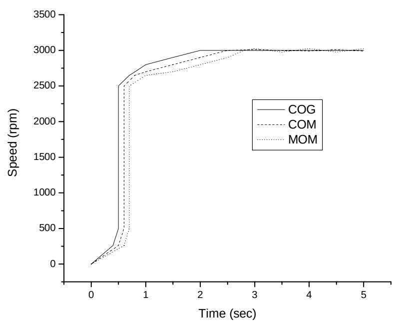

Figure 5

Experimental transient response for defuzzification methods for FLC using three different defuzzification methods

5.3 Effect of Loop-Time Variation

The present system consists of a feedback control system as shown in the VI diagram (Fig. 3). We define the loop-time for this feedback control system as a time for the entire loop. This loop-time is adjustable in the present system with only three possible values, namely 1 msec, 0.1 sec and 1.0 sec. This loop-time is entirely different from the sampling time of the ADC and sample and hold (S/H) circuit in the SCXI 1122 analog input card.

As the SCXI 1122 analog input card works at a sampling rate of 150 kS/s, the sampling period is 1/150, 000 sec (6.7 µsec). This sampling frequency of 150 kS/s is much higher than the frequency of the band limited signal representing the speed of the dc motor (3.3 msec). The sampling frequency is approximately 1000 times the frequency of the band limited signal. The aliasing errors, if any, are taken care of by the anti-aliasing filter in the SCXI 1122 analog input card. The Nyquiste sampling theorem requirement is duly satisfied.

When a 1 msec loop-time is selected, hardly 1000 samples are encountered. The excursions of the speed about the set-point will be very few. Hence the fuzzy logic controller is able to take appropriate decisions and generate corresponding control signals to help the dc motor to run at the set-point speed.

When a loop-time of 0.1 sec and 1.0 sec are chosen, there are approximately 10 Lakhs samples in each loop-time respectively. In such situations, there will be a very large number of excursions about the set-point. Consequently the fuzzy logic controller is utterly confused as to which rule is to be fired in such chaotic conditions. Consquently the fuzzy logic controller takes a long time to control the speed of the dc motor at the desired set-point speed. This is the reason for shortest settling time when we choose 1 msec as the loop-time. The comparison of these three sampling rate is shown in Fig. 6.

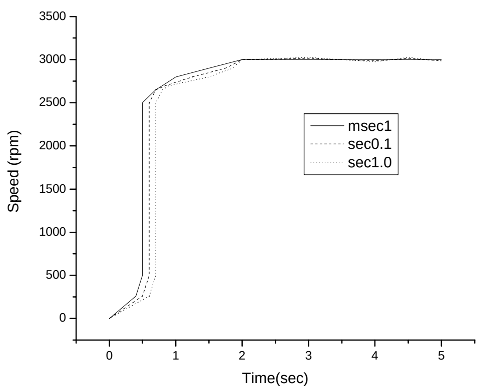

Figure 6

Experimental transient response of speed control for PMDC micro motor using three different sampling rates [m sec1 = 1 m sec sampling time etc]

Conclusions

The FLC has been successfully designed and implemented for the real time speed control of PMDC micro motor for a desired speed of 3000 rpm. The results for the best choices of number of triangular membership functions for fuzzification, defuzzification methods and different sampling rates were obtained. From the experimental transient response, we conclude that for robust, flexible, faster and real time speed control of PMDC micro motor using FLC technique, the best choices are 7-number triangular membership functions for fuzzification, a COG method for defuzzification and a sampling time of 1 msec.

References

[1] Li Zhang., "A Practical Guide to Tune Proportional Integral (PI) Like Fuzzy Controllers", IEEE Int. Conf. on Fuzzy Systems, **2**, 1992, pp. 630-640

[2] Li Zhang., "A Practical Computer-aided Tuning Technique for Fuzzy Control", IEEE Int. Conf Fuzzy Systems **3**, 1993 pp. 702-707

[3] Xie-Kanglin, J. Fu, "Determination of Membership Functions and Fuzzy Rule of Neural Network FLLC System", Journal of Shanghai Jiaotong Uni, **31(8)**, 1997, pp.28-33

[4] J. L. Castro, "How Many Rules are Necessary to Get Good Fuzzy Controller for a Control Problem?" Proc. of the 6th Int. Conf on Fuzzy Systems, **2**, 1997 pp.749-754

[5] D. P. Filev, R. R. Yager, "A Generalized Defuzzification Method via Bad Distributions", Int. J. of Intelligent System, **6(7)**, 1991 pp. 687-697

[6] D. P. Filev, R. R. Yager, "An Adaptive Approach to Defuzzification Based on Level Sets", Fuzzy Sets and Systems, **54(3)**, 1993, pp. 355-360

[7] R. R. Yager. D. P. Filev, "SLIDE: A Simple Adaptive Defuzzification Method", IEEE Trans. on Fuzzy Systems, **1(1)**, 1993, pp. 69-78

[8] R. R. Yager, D. P. Filev, "On the Issues of Defuzzification and Selection Based on a Fuzzy Sets", Fuzzy Sets and Systems, **55(3)**, 1993, pp. 255-272

[9] S. Mabuchi, "A Proposal for a Defuzzification Strategy by the Concept of Sensitivity Analysis", Fuzzy Sets and Systems, **55(1)**, 1993, pp. 1-14

[10] W. Pedrycz, "Fuzzy Control and Fuzzy Systems Research Studies", John Wiley and Sons, N.Y. 1989