Speed control of brushless DC motor using genetic algorithm based fuzzy controller

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Abstract: The brushless DC motor (BLDCM) is receiving wide attention for industrial applications because of their high torque density, high efficiency and small size. Conventional controllers suffer from uncertain parameters and the non-linear of the BLDCM. The fuzzy control has been focus in the field of the control of the BLDCM. However, a systematic method for designing and tuning the fuzzy logic controller is not developed yet. In this paper, an auto-tuning method for fuzzy logic controller based on the genetic algorithm (GA) is presented. And the scheme is applied into the BLDCM control. Two closed loops are constructed in this paper. The inner loop is current feed back which is to adjust the torque of the motor. The outer loop is the fuzzy logic controller whose control rules are optimized off-line and parameters are adjusted based on the genetic algorithm. In this paper, a program is written in Visual C++ to adjust the fuzzy controller off-line. At last, a TMS320LF2407A digital signal processor (DSP) is used to fully prove the flexibility of the control scheme in real time. Excellent flexibility and adaptability as well as high precision and good robustness are obtained by the proposed strategy.

Keywords: Brushless DC motor; Fuzzy control; Genetic algorithms; DSP

1. Introduction

Brushless DC motors are reliable, easy control, and inexpensive. Due to their favorable electrical and mechanical properties, high starting torque and high efficiency, the BLDCM are widely used in most servo applications such as actuation, robotics, machine tools, and so on.

The design of the BLDCM servo system usually requires time consuming trial and error process, and fail to optimize the performance. In practice, the design of the BLDCM drive involves a complex process such as model, devise of control scheme, simulation and parameters tuning. Usually, the parameters tuning for a servo system involves a sophisticated and tedious process and requires an experienced engineer in doing so. Application of intelligent optimization technique in tuning critical servo parameters remains an interesting and important issue to be further studied. Many papers have presented different design approaches and control structures in designing the digital servo controller. In [1] a PI controller has been proposed for BLDCM. The PI controller can be suitable for the linear motor control. However, in practice, many non-linear factors are imposed by the driver and load, the PI controller cannot be suitable for non-linear system. Fuzzy control is a versatile and effective approach to deal with the non-linear and

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uncertain system [2]. Even if a fuzzy controller (FLC) can produce arbitrary non-linear control law, the lack of systematic procedure for the configuration of its parameters remains the main obstacle in practical applications [3-5]. In [5] a FLC for BLDCM has been proposed. But the parameters of the FLC cannot be auto-tuning and not be suitable for difference conditions.

Recently, the design of FLC has also been tackled with genetic algorithm (GA). These are optimization algorithm performing a stochastic search by iteratively processing 'populations' of solutions according to fitness [6]. In control applications, the fitness is usually related to performance measures as integral error, setting time, etc. GA based FLC have been used in induction motor control system design successful [7], but the application in BLDCM servo system is few. Differently from most of previous works [10], this paper evaluates the fuzzy rules by GA, and tuning the parameters of the FLC on-line. At last the GA based FLC has been applied to the control system of BLDCM by using digital signal processor (DSP) TMS320LF2407A. The controller improves the performance and the robustness of the BLDCM servo system.

2. BLDCM Servo System

Fig. I shows the block diagram of the configuration of fuzzy model control system for BLDCM. The inner loop of Fig. I limits the ultimate current and ensures the stability of the servo system. The outer loop is designed to improve the static and dynamic characteristics of the BLDCM servo system. In this paper, a fuzzy control is used to make the outer loop more stable. To make the fuzzy controller more robust, this paper presents the genetic algorithm to optimize the fuzzy rules, and auto-tuning the coefficient of the controller.

Fig. II is the control configuration of the BLDCM servo system. The TMS320LF2407A DSP is used to generate the PWM and an IR2130 is used to drive the MOSFET. The A/D Unit is used to sample the current of the motor. The position signal of the rotor in gained by the Capture Unit of the DSP, and the speed value is calculated from the position information.

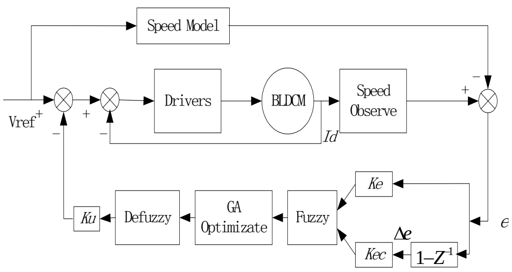

Fig. I Configuration of fuzzy model control system for BLDCM

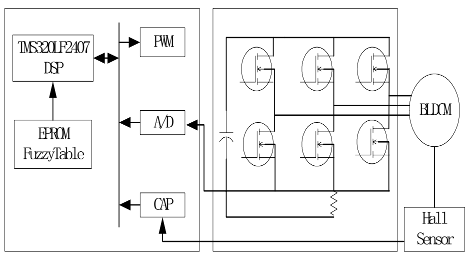

Fig. II Control configuration of the BLDCM

3. Fuzzy Control

Fuzzy logic provides an approximate effective mean of describing the behavior of some complex system. Unlike traditional logic type, fuzzy logic aims to model the imprecise modes of human reasoning and decision making, which are essential to our ability to make rational decisions in situations of uncertainty and imprecision.

Fig. I shows the block diagram of speed control system using a fuzzy logic controller. The most significant variables entering the fuzzy logic speed controller have been selected as the speed error and its time derivative. The output this controller is U. The two input variables *e* (speed error) and e_c (change in error) are calculated at each sampling time as

$$\begin{aligned} e(k) &= n^*(k) - n(k) \\ ec(k) &= e(k) - e(k-1) \end{aligned} \tag{1}$$

Where $n^*(k)$ is the reference speed that time, and $n(k)$ is the actual rotor speed at that sampling.

The FLC consists of three stages: fuzzy, rule execution and de-fuzzy operations.

3.1 Fuzzy Operation

In this stage, the crisp variables are converted into fuzzy variables as

$$\begin{aligned} E &= K_e e \\ EC &= K_{ec} ec \\ U &= u / K_u \end{aligned} \tag{2}$$

In (2), K_e and K_{ec} are the proportion coefficients. They transform the inputs to universe of fuzzy sets. And use K_u to transform the output of the fuzzy control to actual control value. These transformations are closely according to the prescribed membership functions associate with the control variables, the membership functions have been chosen with triangular shapes as shown in Fig. III.

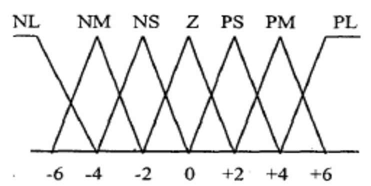

Fig. III The shape of membership function for fuzzy logic

The universe of discourse of input variables and e_c and output U are divided from –6 to +6. Each universe of discourse is divided into seven fuzzy sets: NB, NM, NS, Z, PS, PM and PB. Each fuzzy variable is a member of the subsets with a degree of between 0 (non member) and 1 (full member) as

$$\mu_A(x) = \begin{cases} 1 & if\ \mu_A \in A \\ 0 & if\ \mu_A \notin A \end{cases} \tag{3}$$

3.2 Rule Execution

The fuzzy rules are actually experience rules based on expertise or operators' long-time experiences. Table I shows the fuzzy rules. The variables are processed by an inference engine executes 49 rules (7*7). Each rule is expressed in the form as

If e is NB and e_c is PM then U is PM

If e is PM and e_c is NB then U is PS

If e is NS and e_c is NM then U is PM

……………

TABLE I
THE FUZZY LINGUISTIC RULE TABLE

e	e_c						
	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	NM
NM	PB	PB	PM	PS	PS	ZE	NM
NS	PB	PM	PS	PS	ZE	NS	NB
ZE	PB	PS	PS	ZE	NS	NS	NB
PS	PB	PS	ZE	NS	NS	NM	NB
PM	PM	ZE	NS	NS	NS	NM	NB
PB	PM	NS	NS	NM	NM	NB	NB

3.3 De-fuzzy Operation

In this stage, a crisp value of the output variable U is obtained by using the de-fuzzy method, in which the centroid of each output membership function for each rule is first evaluated. The final output is then calculated as the average of the individual centroid.

4. Genetic Algorithms

GA is a stochastic optimization algorithm is originally motivated by the mechanisms of natural selection and evolutionary genetics. The GA serves as a computing mechanism to solve the constrained optimization problem resulting from the motor control design where the genetic structure encodes some sort of automation. The basic element processed by a GA is a string formed by concatenating sub-strings, each of which is a binary coding (if binary GA was adopted) of a parameter. Each string represents a point in the search space.

The Selection, Crossover and Mutation are the main operations of GA.

Selection directs the search of Gas toward the best individual. In the process, strings with high fitness receive multiple copies in the next generation while strings with low fitness receive fewer copies or even none at all.

Crossover can cause to exchange the property of any two chromosomes via random decision in the mating pool and provide a mechanism to product and match the desirable qualities through the crossover.

Although selection and crossover provide the most of the power skills, but the area of the solution will be limited. Mutation is a random alternation of a bit in the string assists in keeping delivery in the population.

The optimization step of GA is follow:

A. Code the parameter
B. The initialization of the population
C. Evaluate the fitness of each member
D. Selection

E. Crossover
F. Mutation
G. Go to step1 until find the optimum solution.

5. GA based Fuzzy Controller

Since the fuzzy inference is time-consuming, and the DSP used in motor control is speed-limited, so real-time inference method cannot be chosen. Here by using the synthetic fuzzy inference algorithm, the computer makes a query table off-line in advance and stores it in the memory of DSP. In a practical control, the control value can be obtained according to the query table, and tuning the K_e, K_{ec} and K_U on-line.

The design of the fuzzy controller is base on the genetic algorithm. Fig. IV shows the coding formulation when using GA to optimize the fuzzy controller. Here using 10 bits binary code to denote one fuzzy inference rule. The first binary code is the flag whether the rule is used. The 2~4, 5~7 and 8~10 refer to the error, change in error and the output variable. And001,010,011,100,101,110 and 111 refer to NB, NM, NS, ZE, PS, PM and PB respectively.

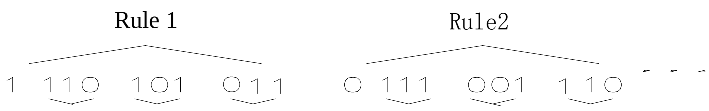

Fig. IV Coding method for GA

TABLE II
THE PARAMETERS OF GENETIC ALGORITHM

Crossover Possibility	0.85
Mutation Possibility	0.002
Generation Numbers	30

TABLE III
THE LINGUISTIC RULE TABLE AFTER OPTIMIZATION

e	e_c						
	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM		PS	PS	NM
NM		PM	PS	PS	PS	ZE	NM
NS	PB	PM	PS	PS	ZE	NS	NB
ZE	PB	PS	PS	ZE	NS	NS	NB
PS		PS	ZE	NS	NS	NM	
PM	PM	ZE	ZE	NS	NS	NB	NB
PB	PM		NS		NM	NB	NB

For example, the first rule of Fig. IV shows that if e is PB and e_c is NB then U is PM, and the first bit binary code '0' indicate that this rule will be eliminated through optimization.

In order to improve the speed of the optimization, this paper chooses 30 candidates as the initialization population, and these candidates are proved to be able to make the motor run steadily.

Table II shows the parameter of GA used in this paper, and Table III shows the fuzzy rules intimidated through GA method. Through the optimization, 6 rules are eliminated and 4 rules are optimized.

6. On-Line Tuning

In order to improve the dynamic performance of the BLDCM servo system, the elements of the query table need to be adjusted according to the input variables. To do this, this paper adjusts the coefficients (K_e, K_{ec} and K_U) to tuning the control system on-line.

The basic principle is the “rough adjustment” and “accurate adjustment”, namely, constantly adjusting the coefficients according to actual e, e_c. If the e and e_c are large, K_e and K_{ec} should be reduced while K_U should be increased because the main objective is diminishing the errors. When e and e_c are small, because the main aim is to diminish the overshoot and steady-state error, K_e and K_{ec} should be increased to increase the resolution of e and e_c while K_U should be reduced to obtain small control value to reduce the overshoot and steady-state error. The adjust function as follow

$$K_e = \begin{cases} K_{e0} + K_1 \times e, & |e| \le \frac{e_{max}}{2} \\ K_{e0} + K_1 \times \frac{e_{max}}{2}, & |e| > \frac{e_{max}}{2} \end{cases} \tag{4}$$

$$K_{ec} = \begin{cases} K_{ec0} + K_1 \times e, & |e| \le \frac{e_{max}}{2} \\ K_{ec0} + K_1 \times \frac{e_{max}}{2}, & |e| > \frac{e_{max}}{2} \end{cases} \tag{5}$$

$$K_u = \begin{cases} K_{u0} + K_1 \times e, & |e| \le \frac{e_{max}}{2} \\ K_{u0} + K_1 \times \frac{e_{max}}{2}, & |e| > \frac{e_{max}}{2} \end{cases} \tag{6}$$

7. Result

In order to verify the validity of the proposed controller, conventional fuzzy controller is compared with GA based fuzzy controller. In the case of changing motor, all the system parameters are varied. Thus, GA fuzzy controller will be adaptable to uncertain control parameters.

A simulation program is designed to compare the stable and dynamic performances. Fig. V and Fig. VI shows the speed curve when the motor speed is 2100r/m. Fig. V is the result of the PID controller, and Fig. VI is the speed curve of the GA based fuzzy controller.

TABLE IV

PARAMETERS OF TESTED MOTOR

Type	70BL1030-12
Voltage	12VDC
Power	120W
Rotate Speed	3000rpm

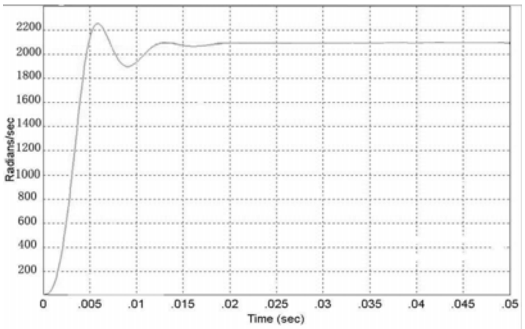

Fig. VI Rotate speed simulation curve when adopting fuzzy controller based on GA

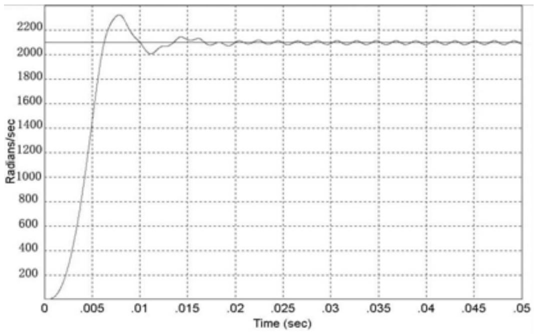

Fig. V Rotate speed simulation curve when adopting tradition PID regulating strategy

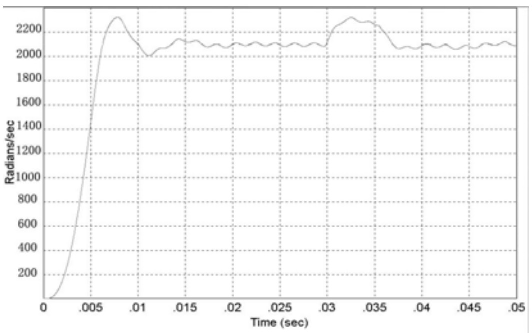

Fig. VII Rotate speed simulation curve using PID controller when

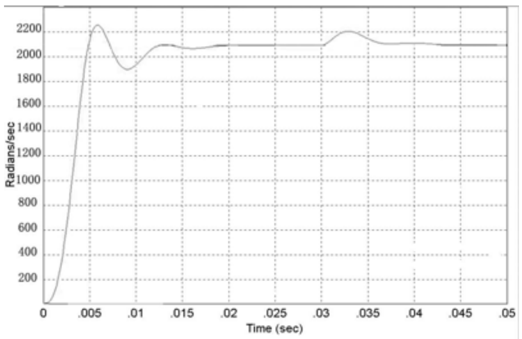

Fig. VIII Rotate speed simulation result using Fuzzy controller based on GA when the load

Fig. V shows that the PID control has bigger overshoot. And Fig. VI shows that GA based fuzzy controller has less overshoot and more stable performance.

This paper simulates the situation when the load is change, Fig. VII shows the motor speed curve using PID and Fig. VIII shows the simulation result when using GA based fuzzy controller. The comparison of the PID and GA based fuzzy controller when the load change shows that fuzzy controller has good dynamic performance. Fig. VIII indicates that the fuzzy controller is much more robust than the PID controller.

In this paper, the GA based fuzzy controller is realized by using TMS320LF2407A DSP, and gain a good performance. Fig. IX and Fig. X show the voltage curve of BLDCM by using the PID controller and GA based fuzzy controller. These figures indicate that the voltage wave shape of the BLDCM is steadier by using GA based fuzzy controller.

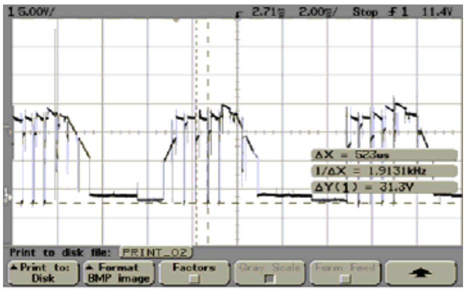

Fig. IX Voltage curve when adopting PID controller

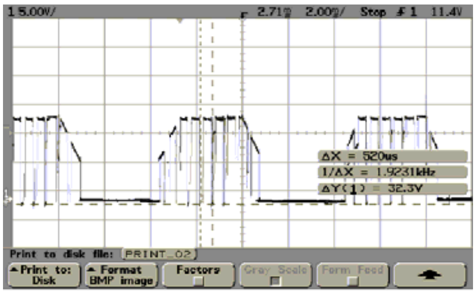

Fig. X Voltage curve when adopting fuzzy controller based on

8. Summary

This paper uses the GA based fuzzy controller as the speed controller of the BLDCM servo system. By comparison with PID controller, it testifies that this method is not only robust, but also can improve dynamic performance of the system. The off-line adjust optimize the fuzzy rules, and the on-line tuning of the parameters of the fuzzy controller make the controller has good dynamic and robust performance.

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