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Design and Implementation of a Digitalized Fuzzy Logic Controller For DC Servo Drives

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Abstract: - In this paper, a high performance of fuzzy logic controller for DC servo motor is developed. The system design and implementation procedure of DC servo motor drive using digital signal processing chip TMS320C14 are described. Some experimental results are shown to verify the proposed controller.

Key-Words: - Fuzzy logic controller, Digital signal processing, DC servo motor

1 Introduction

There are many applications of servo motor [1]-[5], such as numerical control machine tools, industrial robots, medical equipments, office machines, measuring equipments, and computer peripherals. Generally, the equipments and machinery are used to save energy and promote automation, which allows for high productivity and also produces quality products. The equipment is becoming more technical with the application of servo motors, and the needs for characteristics of servo motor are getting more specific, especially more compact, light weight and high output.

DC motors are widely used in many variable-speed drive systems [4]-[5]. The versatile control characteristics of DC motors have contributed to their extensive use in many applications. DC motor can prove high starting torques, which are required for traction drives. Besides, control over a large speed range both below and above the rated speed can be easily achieved. The simplicity and flexibility of control of DC motors have made them suitable for variable-speed drive applications. In fact, a majority of industrial drives today use DC machines.

In recent years, the rapid technological progress in microelectronics and power electronics has clearly had a significant impact on motor control systems and their applications [1]-[2], [6]. Consequently, present trends in servo drive technology are toward fully digital speed and position control and even torque control systems [7]-[14]. The strategy is to utilize the computational power of the microprocessors and their storage capabilities for corrective, decoupling and predictive feed forward control.

Many control algorithms are introduced to get high performance, such as model reference adaptive control [15], self tuning adaptive control [16]-[17], and variable structure control [18]. However, these design methods are always complex and their control generally requires a considerable amount of computation time effective compensation [19]. On the contrary, the fuzzy algorithm [11]-[13], [20]-[21] based on intuition and experience which can be regarded as a set of heuristic decision rules is simple to design. Such no mathematical control algorithms can be implemented easily in a computer, and they are straightforward and should not involve any computational problem. Fuzzy logic controller has been recently found various applications in the industry as well as in household appliance. For complex and/or ill-defined systems that are not easily capture the approximate qualitative aspects of human knowledge and reasoning. Motivation by this viewpoint a design procedure of fuzzy logic controller for DC servo system is presented in this paper.

2 Fuzzy Logic Control System

A typical fuzzy logic controller consists of four components and the descriptions are stated as follows:

1) *Fuzzification Interface:* The fuzzification interface performs a conversion from a crisp point into a fuzzy set. The shapes of the membership functions of the linguistic sets are determined according to the expert experience.
2) *Knowledge Base:* The knowledge base commonly consists two sections: a database and a rule-base. The database contains the membership functions

of the fuzzy sets used in the fuzzy rules and the rule-base contains a number of fuzzy IF-THEN rules.

The canonical fuzzy IF-THEN rules are usually made from the following conditions: (a) Obtaining by the expert knowledge and/or operators' experiences. (b) According to the control behavior of the users. (c) According to the characteristic of the plant. (d) Obtaining by self-learning.

3) *Inference Engine:* The inference engine that performs the fuzzy reasoning upon the fuzzy control rules is the main component of the fuzzy controller. There are varieties of compositional methods in fuzzy inference, such as max-min compositional operation and max-product compositional operation etc.

4) *Defuzzification Interface:* The defuzzification interface converts the fuzzy output of the rule-base into a non-fuzzy value. The center of area is the often used method in defuzzification.

The complete block diagram of the fuzzy control system is depicted in Fig.1. A fuzzy logic controller of two inputs e(kT), ce(kT) and one output △U(kT) is used for the DC motor control system. In view of this figure, e(kT) denotes the error between the pre-defined reference speed (speed command) ω_r, and the motor output speed ω(kT) at time instance kT, where k is a positive integer and T is the sampling interval, ce(kT) denotes the change of the error, and △U(kT) denotes the output change of fuzzy logic controller.

3 Hardware and Software Design

3.1 The DSP chip and power-14 system board

Digital signal processing (DSP) emulates the traditional analog processing methods by implementing filters and feedback systems using the numerical methods. In DSP systems, analog signals are quantized to discrete values using analog to digital converters. After the processing they may be converted back to the analog domain. Digital control is similar to the digital signal processing, with analog hardware being replaced by digital hardware. By surrounding a high performance DSP with applicable I/O, the processor forms a digital signal controller. The TMS320C14 has made digital signal processing affordable for low cost control applications.

Next, the TMS320C14 DSP chip and the Power-14 evaluation tool are introduced [22]-[26]. The TMS320C14 DSP chip is a product of Texas Instruments (TI) Incorporated. The 'C1X family utilizes a modified Harvard architecture for speed and flexibility. In a strict Harvard architecture, program and data memory lie in two separated spaces that permits a full overlap of instruction fetch and execution. The 'C1X family modification of Harvard architecture allows the transfers between program and data spaces, thereby increasing the flexibility of the device. With a 160-ns instruction cycle, these devices are capable of executing up to 6.4 million instructions per second (MIPS). The control-specific on–chip peripherals include two 16 bit timers, a versatile timer event manager (timer capture and compare functions), a watchdog timer, 16 bit digital I/O, and an asynchronous/ synchronous serial interface.

Power-14 system board, a product of Teknic Incorporated, is an evaluation tool for developing control application based upon the TMS320C14 digital signal controller. Power-14 system board consists of a 'C14 processor, emulation hardware providing user downloadable program memory, RS-232 communications hardware, a monitor program which allows display and modification of processor memories, breakpoint hardware, three channel of switching servo-amplifier, and an A/D subsystem.

The I/O configuration logic interfaces the 'C14 event manager to hardware for controlling devices such as motor drive circuit, and for reading feedback from encoders. The I/O logic is broken into two logic blocks: (1) output configuration logic for mapping compare pins to the servo-amplifier drivers, and (2) input logic to map quadrate inputs and an index pulse to timer inputs.

3.2 The hardware configuration

The hardware configuration of the experimental system is shown in Fig.2. This hardware circuit, includes (1) a TMS320C14 single-chip processor, (2) a dead time control circuit, (3) a base drive amplifier, (4) analog input circuit for A/D converter, (5) a class E chopper power circuit (H bridge configuration), and (6) a scale down circuit from tachogenerator to A/D converter.

Using the internal high double precession PWM mode, and we select timer 2 as a count timer. The pulse width of each compared output pin is determined by the associated compare register, while the overall period is determined by the selected timer period register (TPR2). Power-14 system board supports the dead time circuit, the gate drive amplifier circuit, and the power MOSFET circuit.

The output configuration logic provides the proper polarity to the actual servo amplifier totem pole sections and provides protection from software failure which might enable both switches in a servo-amplifier. We choose the "long" PWM as no overlap mode, and then the "dead" time can be adjusted as 160 nanosecond. Depending on the coding of the timers and compare outputs, up to 16 bits of digital to analog conversion can be presented to the servo amplifier.

The tachogenerator voltage is proportional to the motor speed (7 volts/rpm), so the scale down circuit is designed to scale the voltage to the logic voltage levels and to filter out noise and absorb the abrupt voltage caused from the commutation. The cross references of the decimal representation, heximal representation, and the speed units and voltage units are shown in Table 1.

3.3 The software design

The fixed-point processors in the TMS320C1x family are supported by a full set of hardware and software development tools [25], including the unique scan-based real time emulators, software simulators, and an emulation module. Fig.3 shows the software developed environment. The assembly language tools create and use common object format files (COFF). COFF object files contain separated blocks (called sections) of code and data that we can load into different TMS320 memory spaces.

To maximize the manageability and portability of the system software, a modular or top-down design technique will be used [22], [26]-[27]. Top-down design is used to break up a large task into a series of smaller tasks or building blocks, which in turn are used to construct a total system in a level-by-level form. At the end of a top down design process, a number of modules are linked together which, under the control a main program, perform as a complete system. Digital control systems use a number of standard blocks, it is therefore likely that a designer who already has access to one digital control system will want to "borrow" some of its functional building blocks to quickly implement a new, different control unit or reconfigured one. Each software module is written as subroutine with a clear and efficient interface (for parameter passing, stack use, etc) with the main program.

Now, the overall task can be divided as seven parts: (1) start up, initialization, (2) user's interface, read command and call subroutine, (3) the subroutines (functions), (4) interrupt service routine, (5) debug monitor program that help to develop program, (6) control algorithm, (7) program library. To finish this task, the overall program can be composed of seven modules: (1) the main module, it contains the start up vector, interrupt vector polling, the initial control process, and interrupt service routines, (2) the global variables module, this module defines the global variables in data ram, (3) the command module, it can read command from user, such as speed reference, or controller parameters, then call subroutine, (4) the utilities module, it contains I/O interface to power-14 system board, and some useful utilities, (5) the monitor module, it contains debug monitor function, (6) the serial module, it is a program library, and (7) the compensator module, this module is important and it contains control algorithm which is called from the main module, when a servo control is needed.

To implement different algorithms, such as PID control or fuzzy control, we can modify the compensator module, and then link this module with above six modules. Therefore, the different programs will be generated.

4 Experimental Results

Now, some experimental results of the speed control system are presented. The controlled plant is used by the R511T permanent magnet DC servo motor of the Sanyo Denki CO., LTD. The nominal parameters of the DC motor and tachogenerator are given as follows[2]. In Table 2, the symbol P_R denotes the rated output, E_R is the rated armature voltage, and T_R is the rated torque, while the symbol K_{ec} is the voltage gradient of tachogenerator.

The DC power supply of this experiment is fixed as 50 volt, and the PWM chopper frequency is chosen as 8k hertz, or chopping period is 125 micro-second, equivalently. And the servo loop is per 1.025 millisecond. Now, the whole system of DC servo system is established and tested. For the convenience of explanation, the decimal unit is used to represent the speed command. The relationship of various units can be transformed according to Table 1. For example, when the speed command is changed form 0 to 800 in decimal, it is equivalent form 0 to 999.2 micro volts, or form 0 to 770.48 rpm.

Form section 2, it is apparent that the parameters of the fuzzy logic controller are: (1) The set of input and output variables (i.e., the controller structure), (2) The set of linguistic rules, and (3) The fuzzy language. The mathematical operations are chosen for classification (i.e., mapping from a measurement to a fuzzy set), composition (evaluation of induced fuzzy restriction of the output) and interpretation (i.e., mapping of the output fuzzy set to a specific control action) are also of significance and are the indirect parameters of the controller.

The control rules of the DC servo system are shown in Table 3. In these control rules, seven linguistic fuzzy sets are applied for all the input and output fuzzy variables. These fuzzy sets are shown as: NB (negative big), NM (negative medium), NS (negative small), PB (positive big), PM (positive medium), PS (positive small), and ZE (zero).

In the control rules, the linguistic fuzzy sets are used to describe the system variables. We must define membership function to describe the fuzzy set for fuzzification. The membership function is defined as shown in Fig.4, which is applied to all the input and output fuzzy sets. The universal sets E,CE, and U are all defined on the interval [-6, 6], and the centre point of the fuzzy sets NB, NM, NS, ZE, PS, PM, PB, are -6, -4, -2, 0, 2, 4, 6, respectively.

Next, the experiment results are given. Fig.5 shows the response waveform of fuzzy logic controller when speed command is from 0 to 800. In view of this figure, it has no overshoot and it has the smaller settling time.

Fig.6 shows the step response waveform when speed command is changed from -800 to 800.

Finally, the speed command is changed from high speed to low speed, say, from 800 to 10, the response is shown in Fig.7. Obviously, these experiment result are satisfactory.

5 Conclusion

In this paper, design and implementation procedures of a high performance fuzzy logic controller using TMS320C14 DSP chip for DC motor drive system have been presented. Since the uncertainty, external disturbance, and nonlinear phenomena are always existed in the actual servo systems, a digitalization fuzzy logic controller is proposed to further obtain the good dynamic speed responses. The presented controller is to make the system with tracking ability and make it more robust. Finally, the satisfactory performance of the proposed controller is confirmed by the experimental result in control applications.

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References:

[1] Y. Dote, *Servo Motor and Motion Control Using Digital Signal Processors*, New Jersey: Prentice-Hall, 1990.

[2] P. C. Sen, "Electric motor drives and control-past, resent, and future," *IEEE. Trans. on Industrial Electronics*, Vol. IE-37, No. 6, pp.562-575, December 1990.

[3] *DC Servo Motor, Super R Series*, Catalogue of Sanyo Denki CO., LTD., 1992.

[4] P.C. Sen, *Thyristor DC Drives*, New York: Wiely and Sons Inc., 1981.

[5] T. Kenjo and S. Nagamori, *Permanent-Magnent and Brushless DC Motors*, New York: Oxford, 1985.

[6] P. Vas, *Vector Control of AC Machine*, New York: Oxford, 1990.

[7] A. Nabel, S. Ogasawara, and H. Akagi, "A novel control scheme for current-controlled PWM inverters," *IEEE Trans. on Industry Applications*, Vol. IA-22, No. 4, pp. 697-701, July/August 1986.

[8] H. W. V. D. Broeck, H. C. Skudelny, and G. V. Stank, "Analysis and realization of a pulse width modulator base on voltage space vectors," *IEEE Trans. on Industry Applications*, Vol. IA-24, No. 1, January/February 1988.

[9] C. Marchand and A. R. D. D. Ceng, "Optimal torque operation of digitally controlled permanent synchronous motor drives," *IEE Proceedings-B*, Vol. 140, No. 3, pp 232-240, May 1993.

[10] M. Braae and D. A. Rutherford, "Selection of parameters for a fuzzy logic controller," *Fuzzy Set and Systems*, Vol. 2, pp. 185-199, 1979.

[11] C. C. Lee, "Fuzzy logic in control system: fuzzy logic controller-part I," *IEEE Trans. on Systems, Man, and Cybernetics*, Vol. SMC-20, No. 2, pp. 404-418, March/April 1990.

[12] C. C. Lee, "Fuzzy logic in control system: fuzzy logic controller-part II," *IEEE Trans. on Systems, Man, and Cybernetics*, Vol. SMC-20, No. 2, pp. 419-435, March/April 1990.

[13] C. H. Chou and H. C. Lu, "Design of a real-time fuzzy controller for hydraulic servo systems," *Computers in Industry*, Vol. 22, pp. 129-142, 1993.

[14] Y. Desheng and Y. Rong, "Grey predictor controller for DC speed-control system," *The Journal of Grey System*, Vol. 2, pp. 189-215, 1990.

[15] N. Matsui, "DSP-based adaptive control of brushless motor, " *IEEE Trans. on Industry Applications*, Vol. IA-28. No. 2, pp. 448-454, March/April 1992.

[16] S. Weerasooriya and M. A. EI-Sharkawi, "Adaptive tracking control for high performance DC drives," *IEEE Trans. on Energy Conversion*, Vol. EC-4, No. 3, pp. 502-508, September 1989.

[17] M. A. Ei-Sharkawi and S. Weerasooriya, "Development and implementation of self-turning tracking controller for DC motors," *IEEE Trans. on Energy Conversion*, Vol. EC-5, No. 1, pp. 122-128, March 1990.

[18] T. L. Chern and Y. C. Wu "Design of brushless DC servo systems using integral variable structure approach, " *IEE. Proceeding B*, Vol. 140, No. 1, pp. 27-34, January 1993.

[19] Y. F. Li and C. C. Lau, "Development of fuzzy algorithms for servo systems," *IEEE Control System Magazine*, pp. 65-71, April 1989.

[20] Y. C. Lin, J. Y. Lai, and H. L. Tsay, "Theoretical and experimental study on the application of fuzzy logic control to a DC servo motor system," *The first National Symposium on Fuzzy Set Theory and Applications*, Taiwan, pp. 80-86, 1993.

[21] F. V. D Rhee, H. R.V. N. Lemke, and J. G.. Dijkman," Knowledge based fuzzy control of systems," *IEEE Trans. on Automatic Control*, Vol. AC-35, No. 2, pp. 148-152, February 1990.

[22] K. S. Lin, *Digital Signal Processing Applications with the TMS320 Family Theory, algorithm, and Implementations, Volume 1*, Texas Instruments Inc., 1989.

[23] *TMS320c1x User's Guide*, Texas Instruments Inc., 1991.

[24] T. Bucella and D. Sewhuk, *The Power-14 User Manual*, New York: Teknic Inc., December 1991.

[25] *TMS320 Fixed-point DSP Assembly Language Tools User's Guide*, Texas Instruments Inc., December 1991.

[26] D. S. Thomas and T. Battley, *The Power-14 Demonstrations*, New York: Teknic Inc., October 1990.

[27] D. S. Rashid, T. Bucella, and T. Battley, *Power-source Manual*, New York: Teknic Inc., December 1990.

[28] M. H. Rashid, *Power Electronics Circuits, Devices, and Applications*. New Jersey: Prentice-Hall, 1988.

[29] G. K. Dubey, *Power Semiconductor Controlled Drives*, New Jersey: Prentice Hall, 1989.

[30] D. M. Brod and D. W. Novotry, "Current control of VSI-PWM inverters," *IEEE Trans. on Industry Applications*, Vol. IA-21, No.4, pp. 562-570, 1985.

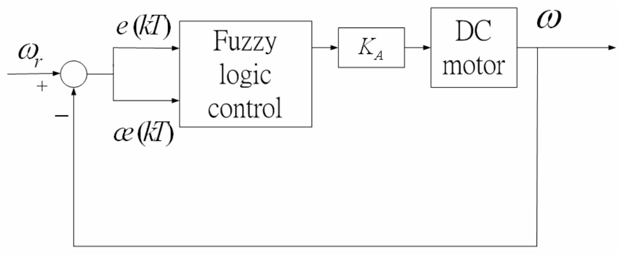

Fig.1 The fuzzy logic control system.

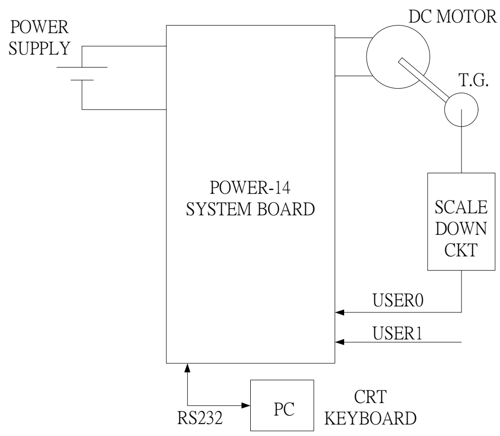

Fig.2 The hardware configuration.

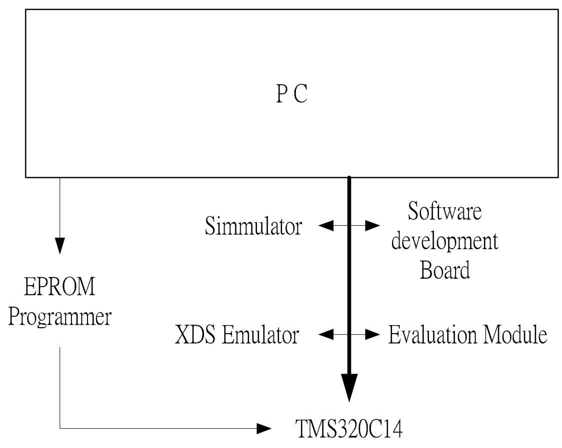

Fig.3 The software developed environment

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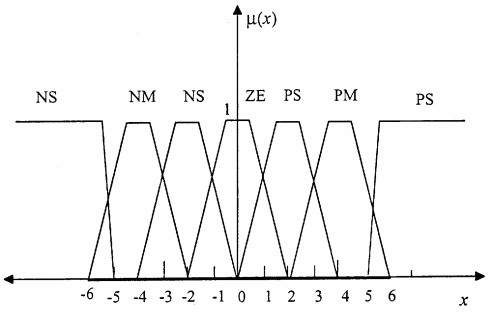

Fig.4 The membership function

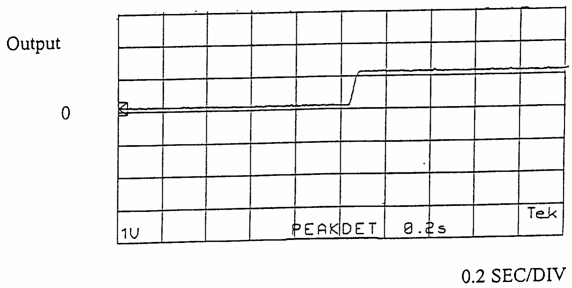

Fig.5 The step response of fuzzy controller Speed=0 to 800.

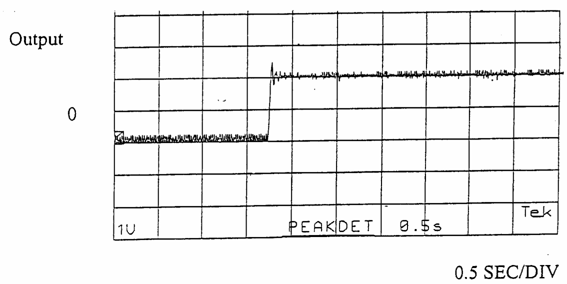

Fig.6 The step response of fuzzy controller Speed= -800 to 800.

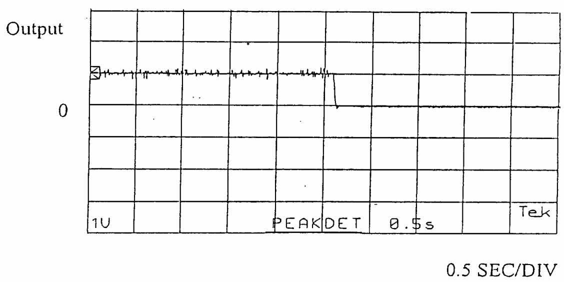

Fig.7 The response of fuzzy controller Speed= 800 to 10.

Table 1 The cross reference table.

D	H	rpm	mV
2,047	07FF	1,971	2,556.7
800	0320	770.48	999.2
1	1	0.96	1.25
0	0	0	0
-1	FFFF	-0.96	-1.25
-800	FCE0	-770.48	-2,556.7

Table 2 The control rule.

ce/e	PB	PM	PS	ZE	NS	NM	NB
PB	ZE	NS	NS	NM	NB	NB	NB
PM	PS	ZE	NS	NS	NM	PB	NB
PS	PS	PS	ZE	NS	NS	NM	PB
ZE	PM	PS	PS	ZE	NS	NS	NM
NS	PB	PM	PM	PS	ZE	NS	NS
NM	PB	PB	PM	PS	PS	ZE	NS
NB	PB	PB	PB	PM	PS	PS	ZE

Table 3 Parameters of motor and tachogenerator

Items	Spec. No.	TYPE : R511(T)-002	
motor	P_R	110	w
	E_R	75	volt
	T_R	3.5	kg.cm
	R_a	4.91	ohm
	L_a	3.00	mH
	K_t	1.93	kg.cm/amp
	K_e	19.76	volt/krpm
	J_m	0.38	g.cm.sec^2
tachogenerator	K_{ec}	7	volt/krpm
	J_m	0.12	g.cm.sec^2