Design of Adaptive Fuzzy Logic Controller for Speed Control of AC Servo Motor

Jing-Rak Nam, Min-Chan Kim, Ho-Kyun Ahn, Gun-Pyong Kwak and Chin-Young Chung, *Member, KIMICS*

Abstract—In this paper, the adaptive fuzzy logic controller(AFLC) is proposed, which uses real-coding genetic algorithm showing a good performance on convergence velocity and diversity of population among evolutionary computations. The effectiveness of the proposed AFLC was demonstrated by computer simulation for speed control system of AC servo motor. As a result of simulation for the AC servo motor, it is shown the proposed AFLC has the better performance on overshoot, settling time and rising time than the PI controller which is used when tuning AFLC.

Index Terms—Fuzzy Control, Adaptive Control, Neural Network, Speed Control, AC Servo Motor

I. INTRODUCTION

Recently, in order to solve optimization problem for control system, many algorithms have been developed. If system is actually nonlinear, correct modeling for system is hard. And extraneous disturbance and measurement error are exist in real system. Therefore, because stability and optimal following are not guaranteed, implementation is not easy. And although modeling error exist, control system should be stable, robust to disturbance and follow to reference input. Hence, adaptive control method is introduced to overcome the above problems. According to change of control system, the gain of PI controller properly is adjusted. And it has many good results and its applications.[1][2]

Because fuzzy controller is designed easily and is available knowledge base design with the robustness to disturbance, it is developed in non-linear system control. [3]

In this paper, new auto-tuning technique is introduced by using evolution operation which is optimization algorithm to based on genetics of nature and evolution theory.

Therefore, adaptive fuzzy logic controller (AFLC) is designed by changing input/output gain of fuzzy controller to get optimal control performance about various disturbance and parameter variation. And input/output gain is obtained in approach of repetition which can adjust through real-coding genetic algorithm with excellent performance about variety of solution and convergence velocity.

Finally, computer simulations results for AC servo motor show the performance improvement of proposed AFLC.

II. DESIGN OF ADAPTIVE FUZZY LOGIC CONTROLLER USING RGA AND NEURAL NETWORK

A. Real-coding genetic algorithm

The main feature of genetic algorithm is sexual reproduction which forms of its own generation gene from parents and evolution principle to happen from the environment.

To solve optimal problem, it need to construct initial population when artificial evolution phenomenon is occurred. The population is formed by many individual in problem space. And it can express bit form to reflect the role of gene. This population is improved by sexual reproduction and gene operator with evolution principle. Hence, each individual can quantify from fitness function.

Usually, genetic algorithm is classified by the bit genetic algorithm and real-coding genetic algorithm (RGA) according to expression of string.

Real-coding genetic algorithm[4] is the real variable coding type which can encode by the real variable that is not string of binary.

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The distinct feature of the real variable coding does not require decoding process and can be applied to mathematical technique.

Fig. 1 shows the configuration of RGA.

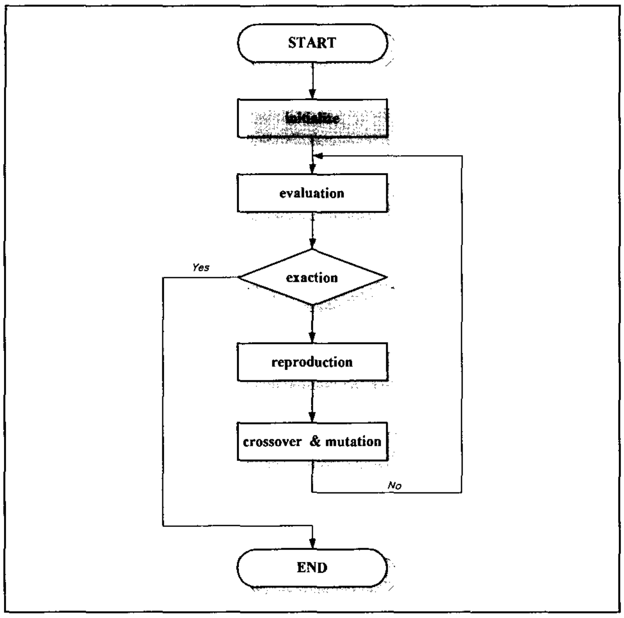


Fig. 1 Configuration of RGA

B. Fuzzy controller

Fuzzy rule of proportional-derivative type is expressed in Table 1.

Table 1. Fuzzy rules of proportional-differential type

e \ de	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	ZO
NM	NB	NB	NM	NM	NS	ZO	PS
NS	NB	NM	NM	NS	ZO	PS	PM
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PM	PM	PB
PM	NS	ZO	PS	PM	PM	PB	PB
PB	ZO	PS	PM	PM	PB	PB	PB

where e is the error, de is the rate of change of the error and PB, PM, PS, ZO, NS, NM, NB are Positive Big, Positive Medium, Positive Small, Zero, Negative Small, Negative Medium and Negative Big respectively.

Defuzzification is converted by the fuzzy value as a result of the fuzzy reasoning.

And the method of defuzzification is one of the max criterion method, mean of maximum method and center of area method.

In this paper, defuzzification is used by center of area method such as Eq. 1

$$U_{cog} = \frac{\sum_{i=1}^{n} \mu(u_i) \cdot u_i}{\sum_{i=1}^{n} \mu(u_i)} \quad (1)$$

where $\mu(u_i)$ is membership position of the fuzzy variable and u_i is the input of the fuzzy variable.

C. Design of adaptive fuzzy controller

The advantage of fuzzy controller is robust to disturbance and variation of system parameter. Therefore, in this paper, adaptive fuzzy logic controller which can obtain optimal performance for disturbance and system parameter. And input/output gain of fuzzy controller uses neural network and changes in every sampling time.

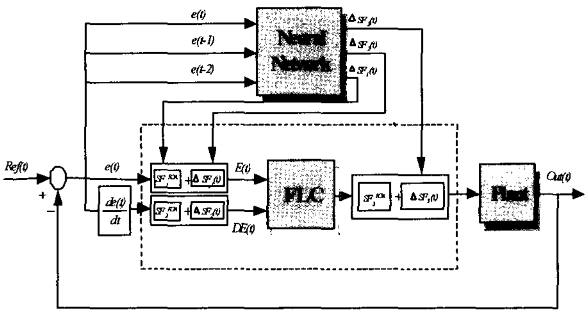


Fig. 2 Configuration for on-line AFLC

In Fig.2, the output of neural network is rate of change to gain of input/output fuzzy controller. And the gain of input/output fuzzy controller is adaptively changed by forward neural network in every sampling time on real time as follows.

$$SF_i(t) = SF_i^{RGA} + \Delta SF_i(t) \quad i = 1, \cdots, 3 \quad (2)$$

where $SF_i(t)$, SF_i^{RGA} and $\Delta SF_i(t)$ represents the input/output gain of fuzzy controller, the input/output gain of fuzzy controller tuned by real-coding genetic algorithm and the rate of change of input/output fuzzy controller gain changed by forward neural network respectively.

For real time operation of AFLC, the structure of forward neural network is shown in Fig. 3. And forward neural network input used error with time delay between reference input and output.

In this paper, forward neural network is composed by three input layer neuron , five hidden layer neuron and three output layer neuron.

And work algorithm is introduced by the real-coding genetic algorithm which can minimize the error between real output value in output layer and reference input with pair of work. At that time, the error is changed by the weighting value. Bias term is added by hidden layer and the input of output layer to improve convergence velocity and speed of work.

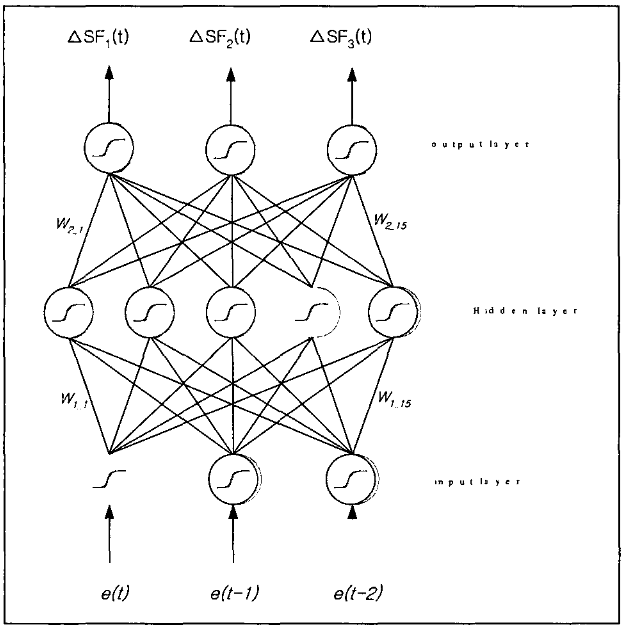


Fig. 3 The structure of forward neural network

III. SIMULATION RESULTS OF AC SERVO MOTOR

To verify the proposed AFLC design technique in this paper, consider AC servo motor.

The specifications of AC servo motor are summarized in Table 2. And simulation coefficients of real-coding genetic algorithm which used AFLC tuning is shown in Table 3.

To show the performance of the proposed algorithm, in maximum overshoot, rising time and settling time, compare AFLC with PI controller tuned by genetic algorithm.

Table 2. Specifications of AC Servo Motor

AC servo motor Parameter	**Rated Power : 400[W], Rated Voltage : 100[V] Phase Voltage : 58[V], Rated Current : 3[A] Rated Speed : 1,800[rpm], Rated Torque : 4.24[Nm] Resistance : 2.3[Ω], Inductance : 13.1[mH]**
Controller Maximum/ Minimum Value	**Maximum Value : 400 Minimum Value : -400**

Table 3. Coefficients for simulation using RGA

Application Method	Number of Population	Probability Crossover	Probability mutation	Run-time (minute)
RGA	30	0.95	0.05	5

Fig. 4 presents the fitness convergence property in every generation. It is clear that by increasing a generation, fitness is improved.

Thus, it is obvious that the proposed AFLC is optimized by the real-coding genetic algorithm.

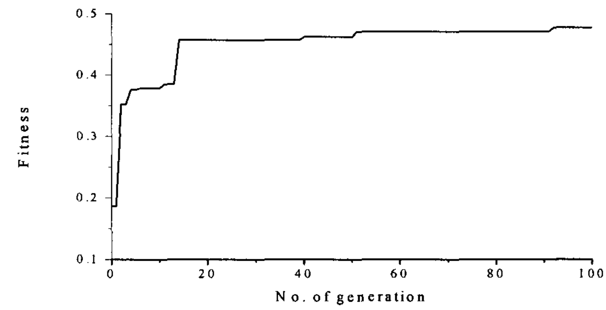
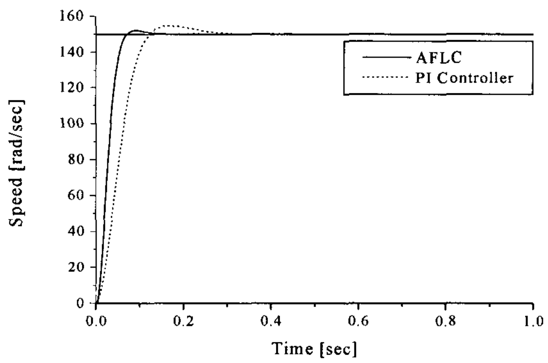


Fig. 4 The change of fitness in each generation

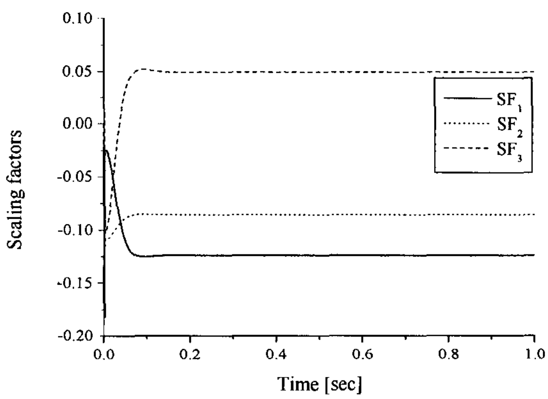
The performance is classified by the condition of AFLC between design and robustness evaluation.

The dynamic simulation results for the robustness evaluation of AFLC in Fig. 3.2, Fig. 3.3 and Fig. 3.4 are shown by the comparison of PI controller when motor speed is 150, 100, 200[rad/sec] respectively.

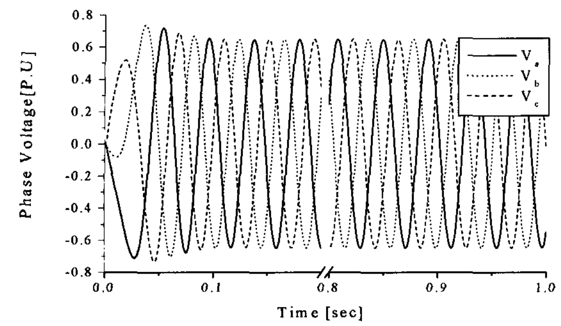
When the step disturbance is applied with 0.5s. in 150[rad/sec], the comparison between AFLC and PI controller is represented. For maximum overshoot, rising time and settling time, AFLC is more robust than PI controller with genetic algorithm.



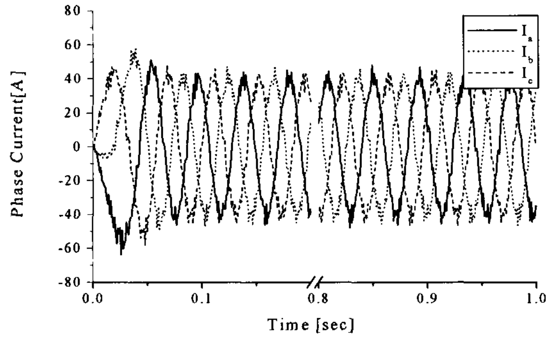
(a) speed response



(b) variation of input/output with AFLC



(c) phase voltage



(d) phase current

Fig. 5 Responses for AC servo motor system when the speed is 150[rad/sec]

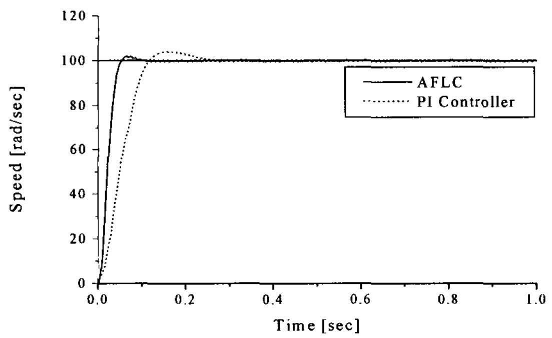


Fig. 6 Responses for AC servo motor system when the speed is 100[rad/sec]

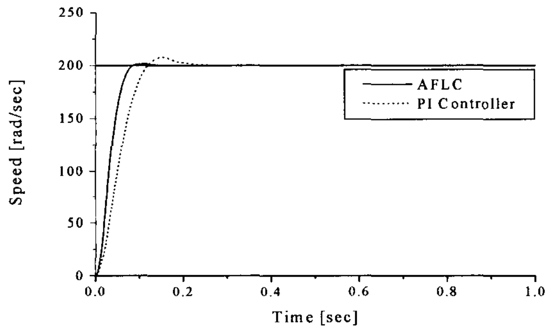
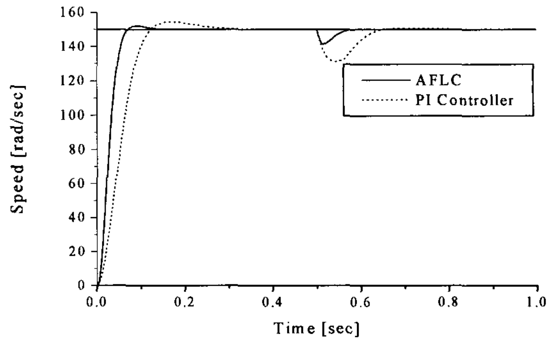
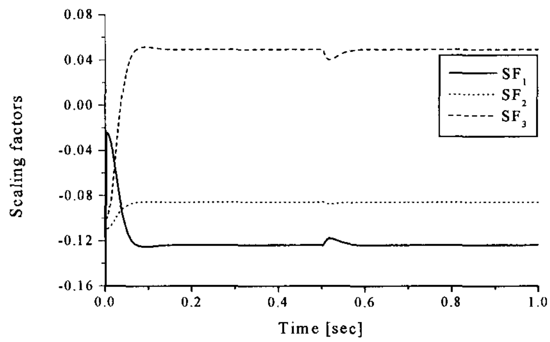


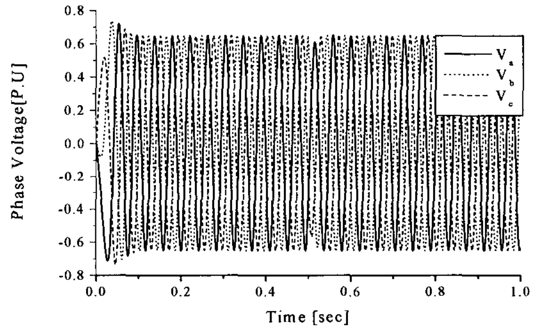
Fig. 7 Responses for AC servo motor system when the speed is 200[rad/sec]



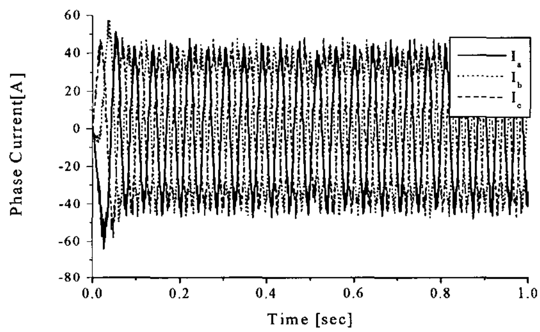
(a) speed response



(b) variation of input/output with AFLC



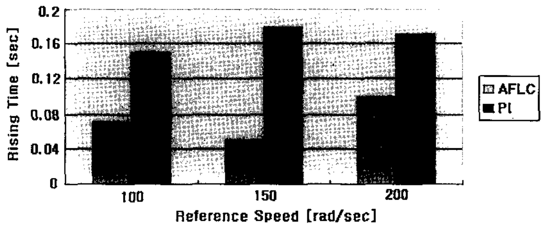
(c) phase voltage



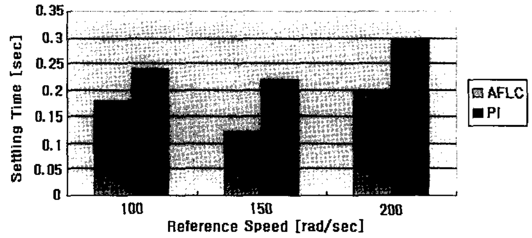
(d) phase current

Fig. 8 Responses for AC servo motor system when the disturbance is applied with 0.5[sec]

For reference speed variation and step disturbance, it can be seen that the proposed AFLC has faster rising time (0.07~0.13s) and settling time (0.06~0.1s) than PI controller with genetic algorithm in Fig. 3.6.



(a) rising time



(b) settling time

Fig. 9 control performance comparison between AFLC and PI controller

IV. CONCLUSIONS

In this paper, adaptive fuzzy logic controller is proposed by using real-coding genetic algorithm.
And the design method is obtained by the input/output gain with real-coding genetic algorithm and tuning of the weighting function with neural network.

A real-time changing method is also proposed by the input/output gain of fuzzy controller with neural network.

For simulation results of AC servo motor, the proposed AFLC has more effective control performance than PI controller with genetic algorithm.
Therefore, it can be expected that the proposed control technique can be applied to the industrial applications.

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