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AC 서보 모터의 속도 제어를 위한 뉴로-퍼지 제어기 설계

(Design of A Neuro-Fuzzy Controller for Speed Control Applied to AC Servo Motor)

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요 약

본 논문에서는 기본적인 형태는 퍼지 제어의 형태를 유지하면서 그 세부적 요소들을 신경회로망으로 구성한 뉴로-퍼지 제어기를 설계하였다. 뉴로-퍼지 제어기는 퍼지 제어 및 신경회로망 제어가 갖는 장단점을 서로 보완할 수 있도록 하였으며 On-Line상태에서 동조가 이루어지도록 하였다. 본 제어기의 성능을 평가하기 위해서 현재 로봇제어에서 많이 사용되고 있는 교류 서보 전동기의 속도제어에 적용시켰다. 가장 보편적인 제어기인 PID제어기 및 퍼지제어기와 비교실험 함으로써 제어기로서의 안정한 특성을 입증하였다. 특히 로봇처럼 급격한 부하변동에 대응할 수 있는 제어기 설계를 위해 부하를 인가하여 실험을 수행하여 성능을 입증하였다.

Abstract

In this study, a neuro-fuzzy controller based on the characteristics of fuzzy controlling and structure of artificial neural networks(ANN). This neuro-fuzzy controller has each advantage from fuzzy and ANN, respectively. Plus, it can handle their own shortcomings and parameters in the controller can be tuned by on-line. To verify the proposed controller, it has applied to the AC servo motor which is popular item in robot control field. General PID and fuzzy controller are also applied to the same motor so stability and good characteristic of the proposed controller are compared and proved. Especially, the experiment for variable load is investigated and performance result is proved also.

Keywords : Neuro-Fuzzy controller, neurons, back propagation, AC servo motor

I. Introduction

Many researchers have recently studied intelligent controller in order to solve problems with classical methods of control, and what is remarkable of all is Fuzzy Control using expert's knowledge or experience or linguistic variables and Neural Network Control with learning ability[1~3].

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The characteristics of fuzzy control are: First, fuzzy control is a type whose algorithm corresponds to usual language and can embody interactive controller because it easily adapt to vague knowledge of human, and therefore it is easy to understand the structure of controller and to modify control rules, so that learning ability is readily offered. Second, it has a parallel structure of control that control input is determined by control rules with plural forms of IF-THEN. With the structure of control, it can be adapted efficiently to control of plant with nonlinear and complication plant. Third, it is a logic type of control that is based on fuzzy logic and determines control input by inference on a language type of control rules[2, 4~5].

And the characteristics of neural network are: First, with learning ability, neural network can adapt itself to changing control environment and can learn just by the type of input and output. Second, it can work real-time performing random data mapping by parallel distributed processing, and it has robustness for against noises. Third, it does not require difficult theories of control, knowledge of system, or other environment models[3, 6~7].

Fuzzy Control and Neural Network Control have many advantages as above, but fuzzy control also has a drawback that you have to set new control law and membership function every time types of system change even after you set control law and membership function[5]. And neural network has a drawback that while learning, it can easily fall onto local minimum instead of global minimum, and it take much time to make as many neurons learn as how complicated the system[7].

In order to make up for the defects, research on integration of neural network and fuzzy control is under way recently. Using back-propagation learning algorithm, Iwata input fuzzy control rules into multilayed neural networks and showed how to use it for Fuzzy Control. Besides, Horikawa used expert experiences so as to automatically find out Fuzzy rules and then membership function.

The Controllers operating two control systems in parallel has a defect that on-line tuning is impossible to be performed because it take a lot of time to make all parameters and fuzzy rules for controller when system parameter changes the feature of system. And it did not make up for each defect that fuzzy control or neural network has about fast response and stability.

This paper designed a basic type of Neuro-Fuzzy controller that maintains fuzzy control and organizes details in neural network to coordinate merits and demerits of fuzzy control and neural network and make on-line tuning possible.

In order to assess performance of the controller, we applied to speed control of The AC Servo motor and verified its basic characteristic as controller by the comparison experiment with PID controller which is most generally used. Besides, we verified stability for nonlinear system such as load disturbance by changing load in order to check suitability as a linear controller and by experimenting PID controller and Fuzzy controller and their characteristics.

Ⅱ. Neuro-fuzzy controller

2.1 System configuration and servo motor modeling

Speed as in Fig. 1.

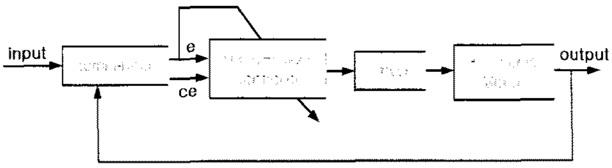


그림 1. 교류서보전동기 속도제어시스템

Fig. 1. Speed control system of the AC servo motor.

Here you can set reference input as $r = u(kT)$, the output of plant as $s = y(kT)$, and T is the sampling period.

The input of Neuro-Fuzzy controller is shown by the output of plant, an error with reference input e(kT) and a change rate of error ec(kT) is defined as the equation(1).

$$e(kT) = u(kT) - y(kT)$$
$$ec(kT) = \frac{e(kT) - e(kT - T)}{T} \quad (1)$$

The following equation(2) shows mathematical modeling of AC Servo motor.

$$e_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t)$$
$$T_m(t) = J_m \frac{d\omega(t)}{dt} + B_m \omega(t) + T_{L(t)}$$
$$e_b(t) = k_b \omega \, T_m(t) = k_t i_a(t) \quad (2)$$

여기서, R_a : 전기자 저항 L_a : 전기자 인덕턴스
e_b : 역기전력 i_a : 전기자 전류
ω : 각속도 e_a : 전기자 전압
J : 관성모멘트

In order to control of AC servo motor based on equation(2) output state variables when used for designing PID controller becomes error of reference speed at equation(3) and real speed.

$$e_\omega = \omega_{ref} - \omega \tag{3}$$

So equation(4) is the conclusions of the AC servo motor speed control system to design of state feedback PID controller.

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -R_a/L_a & -k_b/L_a \\ k_t/J_m & -B_m/J_m \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1/L_a \\ 0 \end{bmatrix} u + \begin{bmatrix} 0 \\ -1/J_m \end{bmatrix} f$$

$$y = [0\,1] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \tag{4}$$

Equation(5) shows transfer function of AC servo motor.

$$\frac{\omega_m(s)}{E_a(s)} = \frac{k_t}{(R_a + L_a s)(B_m + J_m s) + k_t k_b} \tag{5}$$

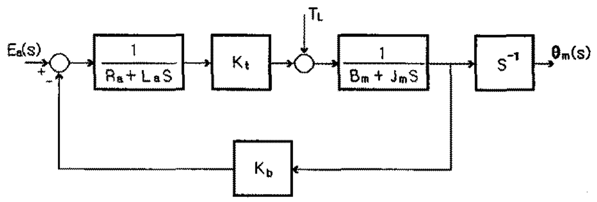


그림 2. 서보전동기의 블록선도
Fig. 2. Block diagram of a servo motor.

2.2 Structure of Neuro-Fuzzy controller

The basic structure of Neuro-Fuzzy controller in this paper takes the form of Fuzzy controller, and separate elements are composed of a neural network. Therefore, as shown in Fig 3 below, the structure of this controller contains the parts of fuzzification, inference engine, and . the parts of defuzzification.

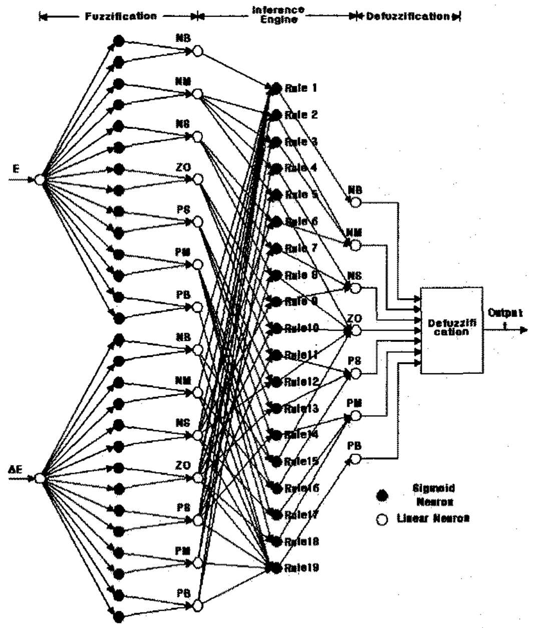


그림 3. 뉴로-퍼지 제어기의 구조
Fig. 3. Structure of Neuro-Fuzzy controller.

2.2.1 Fuzzification

In this paper, Neuro-Fuzzy controller use an error E and change rate of error ΔE as an input signal, both of which are calculated by the comparator. In order to calculate the two input signals through qualitative fuzzy. Fuzzy process, is carried out by means of membership function and nonlinear quantization. As shown in Fig 4, Membership function and nonlinear quantization are adopted in this paper, representing, the narrower the width of membership function and the larger error value, the wider the width of membership function in a specific area of smaller error range. And the membership function is adopted as sigmoid neuron. This process has advantage that more accurate value of membership function can be

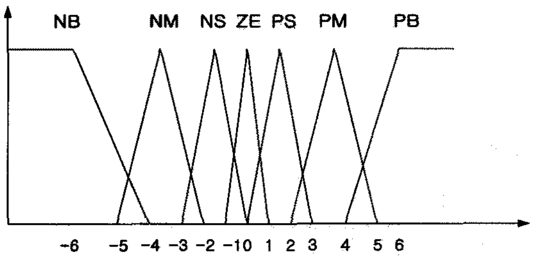


그림 4. 소속함수
Fig. 4. Membership function.

created within short time by reducing countless IF-THEN sentence which created in the process of programming Fuzzy controller.

2.2.2 Inference engine

In this paper, it define the part of qualification as compound proposition and part of conclusion as unity proposition .The general equation (6) is as follow;

$$R_i : IF \quad E \text{ is } A_i \text{ and } \quad CE \text{ is } B_i \quad THEN \quad Z \text{ is } C_i$$
$$for \qquad i=1,2,3,\cdots,n \qquad (6)$$

Here, E is an error, CE is change rate of error and Z is control input. And A_i, B_i, C_i are quantitative linguistic value to each variable. Fuzzy control rule used in this paper is the table 1.

As in this paper, in case that the part of qualification of fuzzy rule is defined as compound proposition, because fuzzy logical AND is adapted among each fuzzy proposition of the part of qualification, fuzzy rule can correspond to nonlinear which result from the coupling of input variables itself. Membership grade of the part of qualification compound proposition can show the fitness of each fuzzy rule. Neuro-Fuzzy controller which was designed in this paper, by arranging sigmoid neuron so as to correspond to each fuzzy rule, ensures link weight each neuron possesses show the fitness of that rule.

표 1. 퍼지규칙
Table 1. Fuzzy rule.

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

2.2.3 Defuzzification

Defuzzification process in this paper adapted method of the center of gravity with the whole excellent quality. This is the method by which you can find the center of gravity in synthesized fuzzy set of output.

The general equation 7 is as follow :

$$u_0 = \frac{\sum_{j=1}^{k} \mu(u_j) \bullet u_j}{\mu(u_j)} \quad \text{n: quantization level} \qquad (7)$$

Ⅲ. Experiment and result examination

In this paper, we applied a Neuro-Fuzzy controller to an AC servo motor speed control generally composed of a mathematical modeling and a linearization to design a nonlinear controller. With the digital servo system made up for that purpose. We compared PID controller and Fuzzy controller as performing with no-load and variable load experiment in the same condition for the evaluation of a tracking capability and stability of Neuro-Fuzzy controller.

3.1 Experimental Devices

Fig. 5 shows an experimental configuration and real pictures of Servo motor. A composed digital

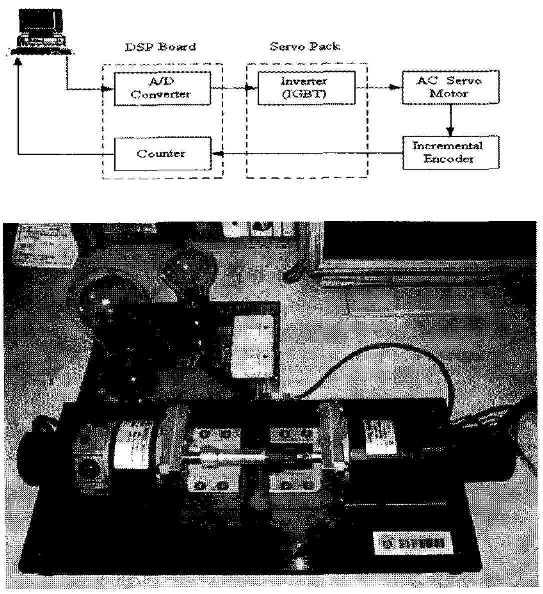


그림 5. 실험장치구성
Fig. 5. Experimental system configuration.

표 2. 교류 서보 전동기의 사양
Table 2. Specification of the AC servo motor.

정격출력	Pr	200 W
정격토크	Tr	6.50 Kgf·cm
정격회전수	Nr	3000 rpm
정격전류	Ir	3.5 A
정격전압	Er	75 V
마찰토크	Tf	0.5 Kgf·cm
기계적시정수	Km	6.25
전기적시정수	Ke	0.48
중량	W	1.9 Kgf

표 3. 서보제어기 사양
Table 3. Servo controller specification.

전원	단상, AC100[V] ±10%, 50/60[Hz]
정격출력전압	±120V Max
정격출력전류	6.5[A]
적용모터용량	50~200[W]

servo system applies a high performance Microprocessor (H8/532) that is way to control a motor revolution as regulating a current supplied in a motor down adjusting a PWM pulse, where PWM frequency is 6.7[kHz].

An amplification for motor operation with a separated power supply (max 75V) used MOSFETs. A digital servo system performs a programming and debugging, then downloading to a operating circuit of a servomotor with a parallel port in IBM-PC.

A motor used in this paper has the maximum power 200[w] and the encoder(1000 resolution) for measurement of speed.

Next table 2 informs the Servo motor specification and table 3 is about Driver of Servo motor specifications.

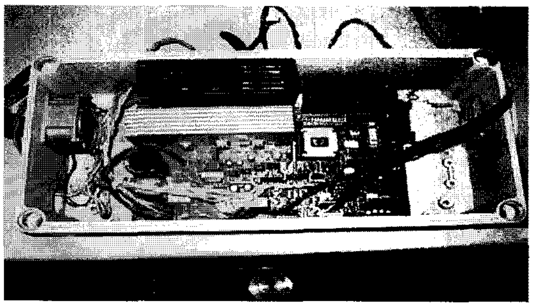


그림 6. 서보전동기의 구동기
Fig. 6. Driver of Servo motor.

Fig .6 shows Driver of Servo motor.

3.2 Experimental Process

The purpose of this paper is to design nonlinear controller having a satisfied performance the cure of system's nonlinear character due to a difficult mathematical modeling of a plant out load disturbance therefore, in this paper we let a designed Neuro-Fuzzy controller apply in the speed control of AC servomotor and etc. To move a performance as a controller and a robustness as comparing PID control the Fuzzy control about load disturbance, we added variable load and had a experiment company that controllers.

The experimental processes are the following;

[1] After let a designed Neuro-Fuzzy controller learn 100 times on the off -line, the link-weight is determined.

[2] The controller performance is proved the controller performance by the (counter) clockwise revolution and variable speed comparison experiment of a PID controller and Fuzzy controller on no-load.

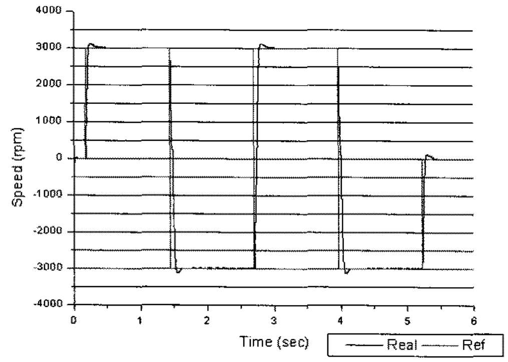
[3] We choose the plant a generator and load in the parallel on the axis of a AC servomotor. Being the comparison experiment of the Neuro-Fuzzy controller, PID controller and Fuzzy controller as being a big and small by turns, It shows that the Neuro-Fuzzy controller has a better performance than others

3.3 Result and Considerations

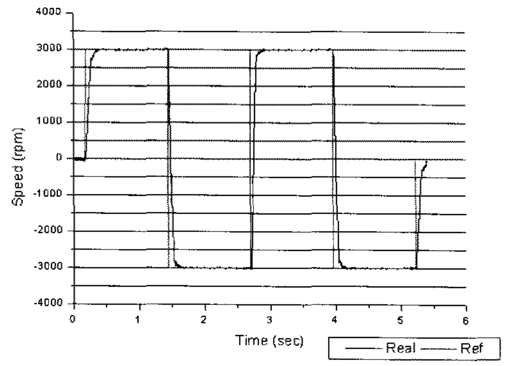
3.3.1 No-load Experiment

[1] *Clockwise Operation Experiment*

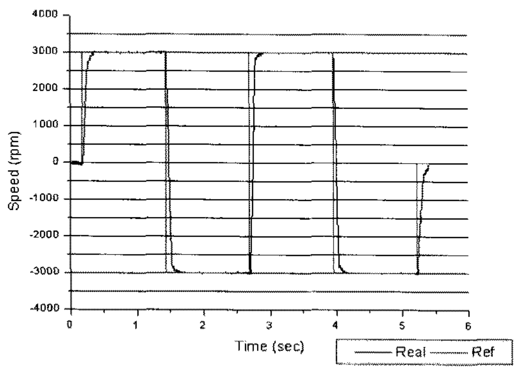
The Fig 7 is the comparison experiment of PID controller, Fuzzy controller and Neuro-Fuzzy controller for the output response by the (counter)clockwise revolution on the no-load of a AC servomotor.



(a) Response of PID controller



(b) Response of Fuzzy controller



(c) Response of Neuro-Fuzzy controller

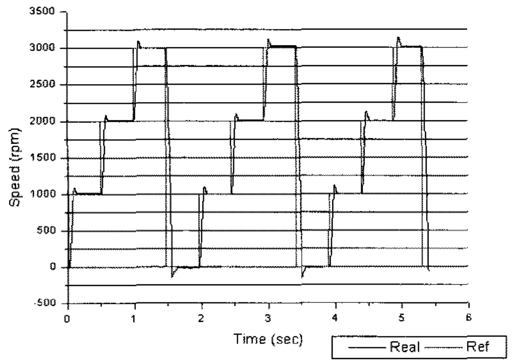
그림 7. 정역운전시 PID,퍼지,뉴로-퍼지 제어기의 출력 응답

Fig. 7. The output response of the PID, Fuzzy and Neuro-Fuzzy controller on a (counter)clockwise.

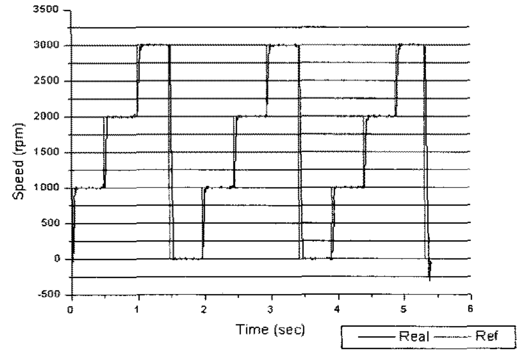
표 4. 실험결과

Table 4. Experimental result.

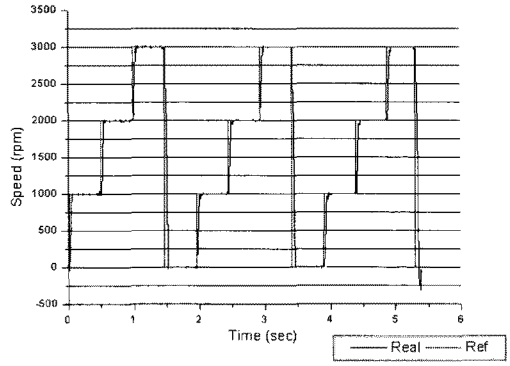
	Clockwise [rpm]	Counter Clockwise	Error between reference input and real output(%)
PID controller	3130	3081	2.7 - 4.3
Fuzzy controller	3004	3002	0.12 - 0.13
Neuro-Fuzzy controller	3004	3002	0.13
	3001	2999	0.06



(a) Response of PID controller



(b) Response of Fuzzy controller



(c) Response of Neuro-Fuzzy controller

그림 8 가변속운전시 PID,퍼지,뉴로-퍼지 제어기의 출력 응답

Fig. 8. The output response of the PID, Fuzzy and Neuro-Fuzzy controller on a variable speed operation.

표 5. 실험결과

Table 5. Experimental result.

	1st	2nd	3rd	Error(%)
PID controller	1089	1097	1105	3
	2088	2097	2121	3.4
	3090	3150	3183	6
Fuzzy controller	1013	1015	1012	0.43
	2011	2011	2011	0.36
	3014	3112	3008	0.43
Neuro-Fuzzy controller	1007	1003	1002	0.26
	2010	2005	2001	0.16
	3008	3006	3001	0.05

As a result of the table 4, the output response on the (counter)clockwise revolution showed that the Neuro-Fuzzy controller has about a 4% decreasing error for the PID controller on the same reference input and a 0.06% for the Fuzzy controller.

Also as a motor having the second (counter)clockwise than the first, it is decreased about a 0.06% error more than the first that by the learned-effect

[2] *Variable speed experiment*

The Fig 8 is the comparison experiment of PID controller, Fuzzy controller and Neuro-Fuzzy controller for the output response by the variable speed operation on the no-load of a AC servomotor.

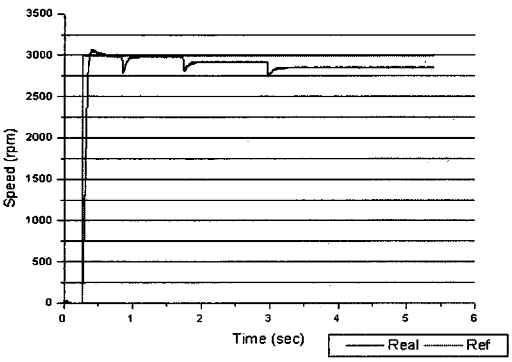
As a result of the table 5, the output response on the variable speed operation showed that the Neuro-Fuzzy controller has about a 3~6% decreasing error for the PID controller on the same reference input and a 0.06% for the Fuzzy controller.

Also as a motor having the second variable speed operation than the first, it is decreased about a 0.1% error more than the first that by the learned-effect and 0.21% than the third that.

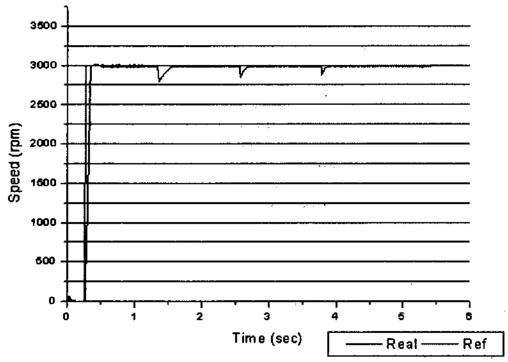
3.3.2 Variable load experiment

The Fig 9 is the comparison experiment of PID controller, Fuzzy controller and Neuro-Fuzzy controller with the variable load. The load having three bulbs (100[w]-200[w]-300[w] by turns) is connected with a generator connected on the axis of AC servomotor in the parallel. The table 3.4 shows the experimental methods. As a result of the table 4, the output response on the variable load showed that the Neuro-Fuzzy controller has about a 3~6.6% decreasing error for the PID controller on the same reference input and a 1~3.3% for the Fuzzy controller.

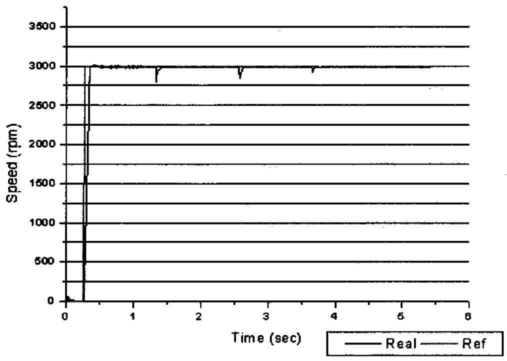
Also as a motor having the second load than the first, it is decreased about a 0.8% error more than the first that by the learned-effect and 3.9% than the third that.. Also PID controller has about a 5~7%



(a) Response of PID controller



(b) Response of Fuzzy controller



(c) Response of Neuro-Fuzzy controller

그림 9. 가변부하시 PID,퍼지,뉴로-퍼지 제어기의 출력 응답

Fig. 9. Variable load response of PID, Fuzzy and Neuro-Fuzzy controller.

표 6. 실험결과

Table 6. Experimental result.

	Load(1) [rpm]	Load(2) [rpm]	Load(3) [rpm]	Error(%)
PID controller	2790	2807	2740	7
				6.43
				8.67
Fuzzy contrller	2874	2890	2897	4.2
				3.67
				3.43
Neuro-Fuzzy controller	2877	2900	2994	4.1
				3.33
				0.2

error for the steady-state recovery time and don't reach at the steady-state. But the Neuro-Fuzzy controller is recovered to steady-state in a only about 0.05 second by the learned-effect.

Ⅳ. Conclusions

The purpose of this paper is to design a Neuro-Fuzzy controller in order to solve the problem being off-line tuning and fuzzy rules producing by a lot of learning time as combining fuzzy control with neural-networks.

This controller is composed with the PID controller and Fuzzy controller as performing the (counter) clockwise revolution and variable speed experiment of the AC servo motor on no-load in order to prove the performance of this new controller and the applied variable load experiment for the tracking capability and the stability in order to be robust with respect to nonlinearity such as disturbance.

The following is the result of this paper in a summary.

[1] In the experiment of a (counter)clockwise revolution and variable speed, the Neuro-Fuzzy controller decreased about a 2.74% error compared with the PID controller.

It decreased the minute vibration in three times learning the same as the Fuzzy controller, the rising times in 0.14 second compared with the PID controller.

Therefore, in the rapid response character on no-load, the Neuro-Fuzzy controller is a little bad compared with PID controller. But in the tracking capability and the stability, it shows the excellent performance.

[2] On applying load as three times in regular interval for response character on variable load, the Neuro-Fuzzy controller decreased the remarkable error compared with the PID controller and Fuzzy controller.

Also after applying load, the Neuro-Fuzzy controller is recovered to the steady-state by the learning of 3~5 time compared with PID controller's keeping the regular error and not reaching to the reference input about the recovery time of the steady-state.

Therefore the Neuro-Fuzzy controller can have a rapid compensational ability for the nonlinear such as the load disturbance.

[3] Compared with the PID controller or the Fuzzy controller let the parameter fixed, the Neuro-Fuzzy controller determining a link-weight by the learning proved having the performance better than two that.

Further studies in this paper are the realization of the faster rising time, the decreased learning time, and the more stable fuzzy-rule.

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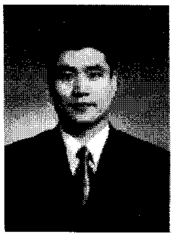
저 자 소 개



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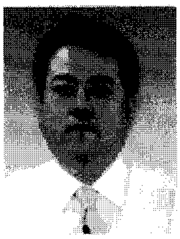

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