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규칙기반 표의 추이 방법을 이용한 퍼지제어기의 성능개선

(The Performance Improvement of Fuzzy Controller using the Shifting Method of Rule Base Table)

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요 약

퍼지논리제어기가 이상적인 제어효과를 나타내게 할려면 적합한 규칙집합을 사용하는 것이 아주 중요하다. 퍼지논리제어기의 언어구조는 가상언어정책을 초기 규칙기반으로 사용하는 것을 허용한다. 만약 설계단계에서 적당한 규칙들을 일정하게 잘 조합시킨다면 제어기의 성능을 훨씬 더 향상시킬 수 있을 것이다. 본 논문에서 퍼지제어기 성능을 개선하기 위한 규칙기반 표에서의 원소추이방법을 제안하였다. 제안된 방법은 에러가 증가되면 시스템을 조절하는 출력의 제어효과가 증대될 것이고 반대로 에러가 감소되면 그에 따른 출력의 제어효과가 감소할 것이라는 원리를 기반으로 하였다. 모의실험결과에 의해 제안된 방법은 퍼지제어 규칙기반과 퍼지논리제어기의 성능을 향상시키기 위한 아주 효과적인 방법임을 알 수 있다.

Abstract

It is essential for a fuzzy logic controller to have an appropriate set of rules to perform at the desired level. The linguistic structure of the fuzzy logic controller allows a tentative linguistic policy to be used as an initial rule base. At the design stage, if one can reasonably assemble a good collection of rules, it may then be possible to be tuned to improve the controller performance. In this paper, we proposed the shifting method of rule base table to improve the performance of fuzzy controller. The proposed method is based on the principle of that the effect of the output to regulate the system would be greater when the error increases and the effect of output would be less when the error decreases. According to simulation results, it is an effective method to improve the fuzzy control rule base and the performance of fuzzy logic controllers.

Keywords: Fuzzy controller, Control rule table, Rules shifting

I. Introduction

Since Zadeh first introduced the concept[1], fuzzy set theory has become a valuable tool for modeling a certain type of uncertainty. Since its introduction there has been a rapid growth in the number and variety of applications of fuzzy logic, ranging from consumer electronics, robotics and industrial process control to decision support systems and financial trading. In spite of this wide variety of applications, the fuzzy logic controller is still the most popular one.

Fuzzy logic controllers model the human decision making process with a collection of rules. Because both the rules and the fuzzy sets used in the rules play a significant role in fuzzy logic controllers, choosing the optimal rules and fuzzy sets becomes an important problem.

When designing a fuzzy logic controller, design

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parameters such as discretization of the universes of discourse, choice of membership functions, decision making logic, etc. need to be determined. However, among all these parameters, assembling an appropriate rule base is the main design problem. Usually the initial rule base is given by the experience of expert or extracted from numerical data of the control procedure. It is difficult to establish a good collection of rules that would result in a desired performance of the application. However, the linguistic structure will allow a tentative linguistic policy to be used as an initial rule base. If one can assemble such a collection of rules, it may then be possible to tune the rule base to get the desired output.

The approach to solve the problem is based on the idea of rule-adaptation. Lee proposed the neuro method to optimize the rule base[2]. Chin and Qi made a special study of learning the rule base using genetic algorithms[3]. A fuzzy controller synthesized through rule adaptation with a direct adaptive approach is proposed by Chen[4]. And there are also many methods using a learning mechanism to gradually construct the fuzzy control rules[5].

The on-line methods were complex and they increased the complicacy of fuzzy controllers. We need a effective, simple and off-line method to optimize the fuzzy rule base.

In a fuzzy control system, as we know, the effect of the output to regulate the system would be greater when the error increases. In reverse, the effect of the output to regulate the system would be decreased when the error decreases. In order to avoid complex mathematical computation, a novel method to tune the rule base based on the principle above is proposed to optimize the fuzzy rule base. The next section introduces the basics of fuzzy if-then rules. Section Ⅲ proposes the rule base table shifting method to optimize the rule-base. Simulation analyses are carried out in Section Ⅳ and conclusions are presented in Section Ⅴ.

Ⅱ. Fuzzy If-Then Rules

The basic structure of a fuzzy logic controller, as illustrated in the Fig.1 consists of three different parts: fuzzification, rule-base, inference and defuzzification.

In the fuzzy control system, the if-then rules are always given by the experience of expert or extracted from numerical data of the control procedure with the form *"If A is positive large(PL) and B is positive large(PL), then C is negative large(NL)"*, where A, B and C are linguistic variables[6], PL and NL are linguistic values that are characterized by membership functions. Usually we call the "if" part and "then" part premise part and

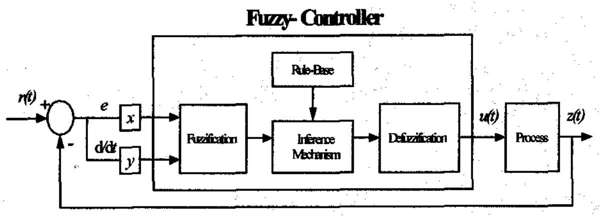


그림 1. 퍼지제어기의 기본 구조
Fig. 1. A Basic structure of fuzzy controller.

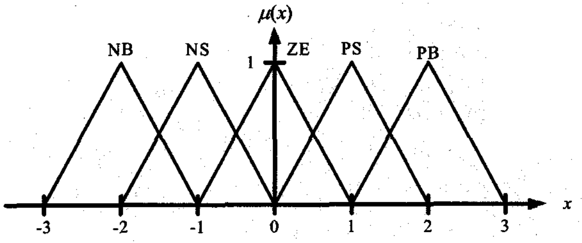


그림 2. 삼각형 꼴의 귀속도 함수
Fig. 2. A triangular-shaped membership function.

표 1. 2개 입력과 5개 언어변수의 규칙기반 표
Table 1. Rule base table for 2 inputs and 5 linguistic values.

u		e				
		NB	NS	ZE	PS	PB
Δe	NB	NB	NB	NB	NS	ZE
	NS	NB	NB	NS	ZE	PS
	ZE	NB	NS	ZE	PS	PB
	PS	NS	ZE	PS	PB	PB
	PB	ZE	PS	PB	PB	PB

consequent part respectively.

The most common fuzzy membership functions to characterize linguistic values are triangles, trapezoids, and gaussian bell curves. The triangles curves is usually used as illustrated in the Fig. 2.

Table 1 shows a typical rule base table where the controller has two input (error e, change of error $\triangle e$) and one output (u). Most of rule tables are symmetrical[7]. But the symmetrical rule table is not always the best one. We can construct a new rule table based on the initial table.

III. Rule Table Shifting Method to Optimize Control Rules

1. The principle of method

Consider a fuzzy logic controller with two inputs error e and error change $\triangle e$, and control u as the output. The fuzzy partition of e, $\triangle e$ and u are given as follows:

$\triangle e$={NB, N, Z, P, PB}, e={NB, N, Z, P, PB},
u={NB, N, Z, P, PB}

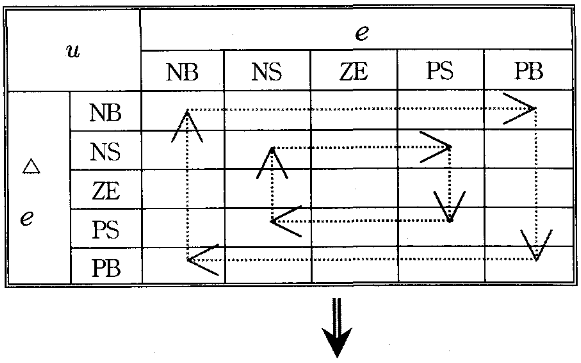
where NB means negative big, N means negative, Z means zero, P means positive and PB means positive big.

Table 1 shows the fuzzy rule base table which includes 25 rules.

The purpose of the fuzzy control system is to minimize the system error $e = |U - u|$. Here, U is the target value and u is the actual output. The effect of the consequent part in outer-circle, composed of e=NB $\vee$PB $\triangle e$=NB $\vee$PB, is to make the output approach the target faster and decrease the rise time. And the effect of the consequent part in inner-circle, composed of e=NS $\vee$PS $\triangle e$=NS $\vee$ PS, is to decrease the system overshoot and keep the stability of system when the actual output almost reaches the target.

Because the initial rule base, given by the experience of expert or extracted from numerical data of the control procedure, is a rough one and can not infer the optimal result, we can shift the consequent terms in outer-circle to adjust the dynamic characteristics and shift the consequent terms in inner-circle to adjust the static characteristics. For example, when we shift consequent terms in outer-circle one unit clockwise and shift consequent terms in inner-circle one unit clockwise of Table.1, we can get Table. 2.

표 2. 표1.의 추이후의 규칙기반 표
Table 2. Rule base table after shifting Table 1.



u		e				
		NB	NS	ZE	PS	PB
$\triangle e$	NB	NB	NB	NB	NB	NS
	NS	NB	NS	NB	NS	ZE
	ZE	NS	ZE	ZE	ZE	PS
	PS	ZE	PS	PB	PS	PB
	PB	PS	PB	PB	PB	PB

Consider the fuzzy control rule base witch is expressed by IF-THEN form:

IF e=X_i and $\triangle e$=Y_j THEN u=$U_{i,j}$.

Here, X_i, Y_j and $U_{i,j}$ is the linguistic values of e, $\triangle e$ and u respectively.

From Mandani inference, we obtain the control value u when x_1, y_1 is input.

$$u_{i,j} = X_i(x_1) \wedge Y_j(y_1) \wedge U_{i,j} \tag{1}$$

We define $W_{i,j}$ as follow:

$$W_{i,j} = X_i(x_1) \wedge Y_j(y_1) \tag{2}$$

And then from neighbor rules we can get the actual output of the fuzzy controller is

$$U = u_{i,j} \vee u_{i,j+1} \vee u_{i+1,j} \vee u_{i+1,j+1} = \\ (W_{i,j} \wedge U_{i,j}) \vee (W_{i,j+1} \wedge U_{i,j+1}) \vee \\ (W_{i+1,j} \wedge U_{i+1,j}) \vee (W_{i+1,j+1} \wedge U_{i+1,j+1}) \tag{3}$$

Consider a fuzzy rule base table which is similar to the Table 1. If the consequent terms is shifted, then the output of fuzzy controller will change to increase or decrease or hold the value, in shifting direction. This can be proofed as follow:

According to formula (3), after shifting one unit we can obtain a new output value

$$U_R = (W_{i,j} \wedge U_{i,j+1}) \vee (W_{i,} \wedge U_{i,j+2}) \vee \\ (W_{i+1,j} \wedge U_{i+1,j+1}) \vee (W_{i+1,j+1} \wedge U_{i+1,j+2}) \tag{4}$$

or

$$U_L = (W_{i,j} \wedge U_{i,j-1}) \vee (W_{i,} \wedge U_{i,j}) \vee \\ (W_{i+1,j} \wedge U_{i+1,j+1}) \vee (W_{i+1,j+1} \wedge U_{i+1,j+2}) \tag{5}$$

From Fig. 2 and Table.1, there are

$$U_{i,j-1} \leq U_{i,j} \leq U_{i,j+1} \leq U-i,j+2 \tag{6}$$

$$U_{i+1,j-1} \leq U_{i+1,j} \leq U_{i+1,j+1} \leq U-i+1,j+2 \tag{7}$$

Compare (3) with (4), (5), we obtain

$$U_L \leq U \leq U_R \tag{8}$$

Apparently, the new table obtained by shifting terms can influence the value of control output. So if we can shift the appropriate direction and units, we can optimize the rule base easily and quickly.

2. Shifting method algorithm

However, for a 5×5 rule table, there are 16 different rule tables by shifting outer-circle of initial rule table and 8 different rule tables by shifting inner-circle of initial rule table. So there are 16*8=128 feasibility. It will be more when rules increase. We need a simpler method to optimize the rule table.

The purpose of shifting rule table is to make $e = \ U-u|$ infinite small. So the consequent terms shift clockwise or anticlockwise and the shifting units according to the error. The steps of the shifting method are proposed as follows:

Step 1. Outer-circle shifting

(1) The controller works using the initial rule table and the value e_0 of $e = \ U-u|$ is obtained.

(2) Shift the consequent terms in outer-circle one unit clockwise and get a new rule table. The controller works using the new rule table and the value e_1 of $e = \ U-u|$ is obtained again.

(3) Compare e_1 and e. If $e_1 < e$, then the consequent terms in outer-circle can be shift one unit clockwise again and obtain the second new rule table. The controller work using the second new rule table. The value e_2 is obtained. If $e_2 < e_1$, continue the clockwise shifting. Stop shifting when $e_{n+1} \geq e_n$ and turn to (5).

(4) In contradiction to (3), if $e_1 < e$, the consequent terms in outer-circle should be shift two units anticlockwise. The controller works using the new rule table and gets the value e_2. If $e_2 < e$, continue the anticlockwise shifting. Stop shifting when $e_{n+1} \geq e_n$ and turn to (5). If $e_2 > e$ too, then the initial rule table is the optimal one.

(5) If $e_{n+1} > e_n$, the rule table correspond to e_n is the optimal one, and if $e_{n+1} = e_n$, the rule table corresponding to e_{n+1} is the optimal one by shifting outer-circle terms.

Step 2. Inner-circle shifting

The procedure of inner-circle shifting is the same as outer-circle shifting.

After finished Step 1 and Step 2, we get a new optimized rule table.

Step 3. Reverse Step 1 and Step 2

Reversing Step 1 and 2 means the inner-circle terms shift first and then the outer-circle terms. Because it may obtain a more optimized rule table. Then we can also get another optimized rule table.

Step 4. Compare and choose

Compare the two rule table above(sometimes, they are identical) by simulation and choose the better one as the final rule base of the fuzzy control system we designed.

Ⅳ. Simulation Results and Comparison

In order to assess the performance of the method above, a water tank fuzzy logic controller to adjust water level was designed. The model function of the system to be controlled is given by the following equations:

$$h=\frac{V_{in}-V_{out}}{Area}$$

$$Area=\pi^{*}R^{2}=A_{k}$$

$$V_{out}=K\sqrt{h}$$

$$V_{in}=f(u)$$

$$h=\frac{f(u)-K\sqrt{h}}{A_{k}}\Rightarrow f(u)=hA_{k}+K\sqrt{h}\quad(9)$$

Here, h is the water level of water tank, $Area$ is the cross section of the water tank, K is the resistance of pipe. The initial rule base of our example is shown as Table 3.

표 3. 탱크제어의 초기 규칙기반 표

Table 3. Intial rule base table of tank controller.

u		e				
		NB	NS	ZE	PS	PB
$\triangle e$	NB	NB	NB	NS	NS	ZE
	NS	NB	NS	NS	ZE	PS
	ZE	NS	NS	ZE	PS	PS
	PS	NS	ZE	PS	PS	PB
	PB	ZE	PS	PS	PB	PB

The fuzzy value of error e, change of error $\triangle e$, and output u are given by Fig. 3, Fig. 4, and Fig. 5. The regions of e, $\triangle e$ and u are chosen to be [-36,36], [-40,40], [-5,1], respectively. And then, we set the initial water as 0, the target water level as 35. The center of gravity method is used in defuzzification.

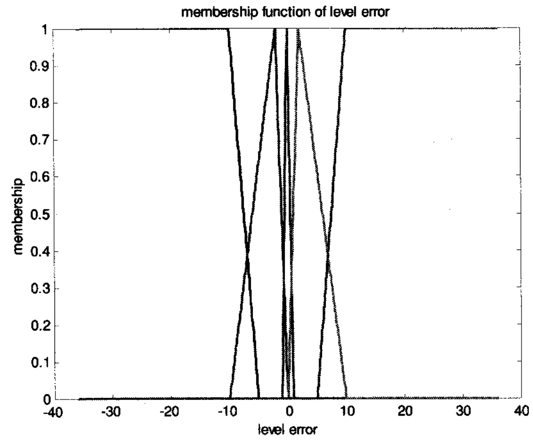


그림 3. 오차에 관한 퍼지 값

Fig. 3. Fuzzy value of error.

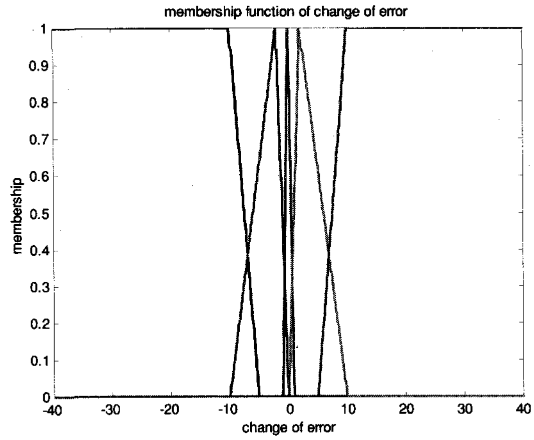


그림 4. 오차 변화에 관한 퍼지 값

Fig. 4. Fuzzy value of change of error.

The simulated response of the water tank system with the initial rule table is shown in Fig. 6 as broken line. It has obvious overshoot and oscillatory behavior with a large steady-state error. It is poor.

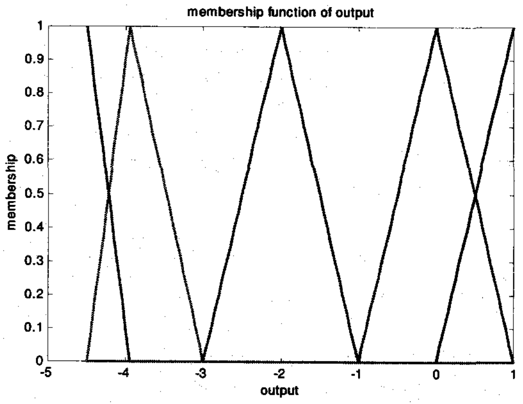


그림 5. 출력에 관한 퍼지 값
Fig. 5. Fuzzy value of output.

표 4. 표3의 추이후의 규칙기반 표
Table 4. Rule base table after shifting Table 3.

u		*e*				
		NB	NS	ZE	PS	PB
△ *e*	NB	NB	NB	NS	NS	ZE
	NS	NB	NS	NS	NS	PS
	ZE	NS	ZE	ZE	ZE	PS
	PS	NS	PS	PS	PS	PB
	PB	ZE	PS	PS	PB	PB

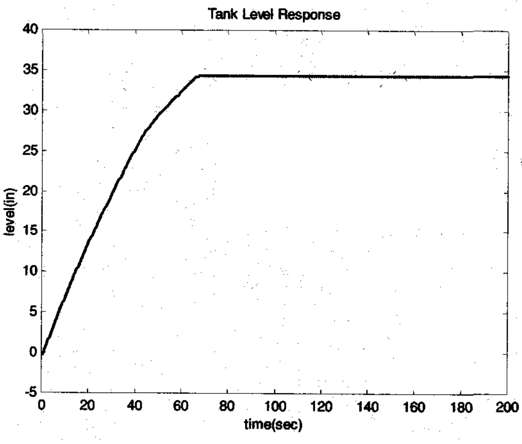


그림 6. 물탱크수위의 응답 곡선
Fig. 6. Response curve of tank level.

Using the shifting method proposed above, the tuned rule base table is shown as Table. 4.

The response of the system with the shifted rule table is shown in Fig. 6 as real line. It improved significantly. There is no overshoot and the steady-state error is very small. It is obvious that the rule base table shifting method is capable of optimizing the performance of fuzzy logic controller.

V. Conclusions

In this paper, a rule base table shifting method of fuzzy logic controller has been presented. It is an effective and simple method to optimize rule base and the performance of fuzzy logic controller, avoiding complex mathematical computation.

A limitation in the performance of the proposed method is that to get an improved rule base depends on the initial rule base to be tuned. In addition, it can not optimize other rule base parameters of fuzzy logic controller. The choice of the shapes of the membership functions has also a great effect on the performance of the system. We can first use the genetic algorithm method[8] or B-spline function method[9] to optimize the shapes of the membership functions. Then the method proposed in this paper can be used at the last design stage for fine tuning after a good collection of rules and the proper membership functions are defined.

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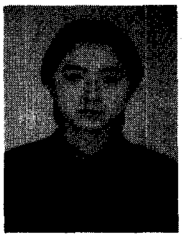
저자소개



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