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SIMULATOR FOR EVALUATION OF VARIOUS FUZZY CONTROL METHODS

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ABSTRACT: As well-known, fuzzy control has been recognized to be of great usefulness in many engineering fields. However, the present design methods of fuzzy control systems depend on trial and error the thing that limits its usefulness. Therefore, an effective and convenient support tools for design and evaluation are greatly needed as well as the establishment of the design methods and guidling. From these backgrounds, we have developed a fuzzy control simulator[1,2] which has various fuzzy control methods such as "direct method", "indirect method" and "fuzzy-PID method". This paper deals especially with the "direct method" function of the simulator. The simulator was developed for personal computers and programed in C language.

KEYWORDS: Fuzzy Control, Fuzzy Inference Methods, Fuzzy Simulator, Evaluating Functions

1. SYSTEM DIAGRAM OF THE SIMULATOR

The system diagram of the simulator is shown in Fig.1. The simulator consists of three parts: "design part", "execution part" and "evaluation part". Firstly, we design a fuzzy controller in the "design part". Secondly, after we set a controlled system in the "execution part", a simulation or an actual control is executed. Lastly, on the basis of the executed results, we evaluate the control performances of the designed fuzzy controller in the "evaluation part". If we are satisfied by the evaluation results, we end the design of the fuzzy controller, otherwise we return to the "design part", and try again the design of the fuzzy controller.

2. FUNCTIONS IN EACH PART

2.1 DESIGN PART

(1) Set of Number of Fuzzy Labelings

For number of fuzzy labelings, we can set the three cases such as 3×3, 5×5 and 7×7 divisions. For example, the 3×3 divisions is that the antecedent and consequent parts are divided into three labelings such as NB (Negative Big), ZO (Zero) and PB (Positive Big) shown in Fig.2.

(2) Set of Fuzzy Control Rules

For control rules, we can select cross type, all area type and user entered type, and give a weight to each control rule. The table of control rules in case of all area type is shown in Table 1.

(3) Decision of Fuzzy Inference Method

By setting several methods in each step of fuzzy inference process, we end to decide a fuzzy inference method.

① Set of Operation Method for Matched Degree (Step1)

For the product operators calculating the matched degrees of antecedent parts, we can set logical product, algebraic product and bounded product.

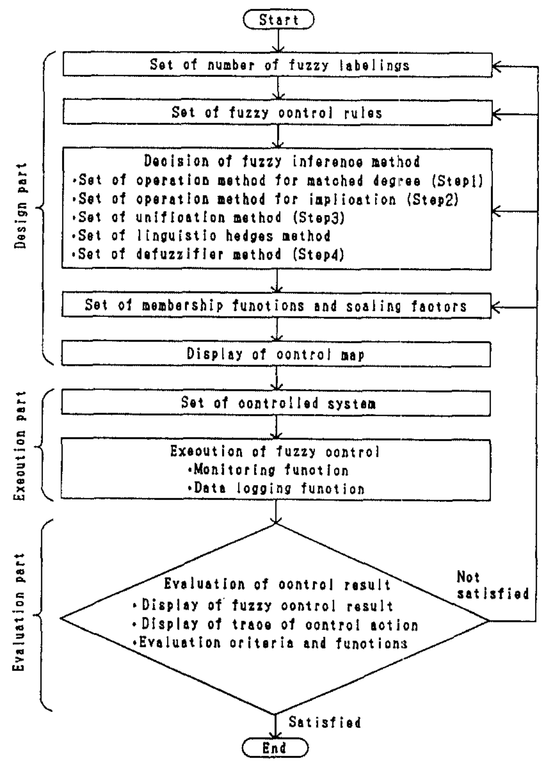

Fig.1 System diagram of the simulator.

② Set of Operation Method for Implication (Step2)

For the operation methods for implication to obtain the inference result of each rule, we set the following (a) methods based on fuzzy products (four kinds) or (b) methods based on implication rules of many valued logic (six kinds).

(a) Methods Based on Fuzzy Products

1) Rc : $a \rightarrow b = a \wedge b$
2) Rp : $a \rightarrow b = a \bullet b$
3) Rbp : $a \rightarrow b = 0 \vee (a+b-1)$
4) Rdp : $a \rightarrow b = \begin{cases} a & \cdots\ b=1 \\ b & \cdots\ a=1 \\ 0 & \cdots\ a,b<1 \end{cases}$

(b) Methods Based on Implication Rules of Many Valued Logic

5) Ra : $a \rightarrow b = 1 \wedge (1-a+b)$
6) Rm : $a \rightarrow b = (a \wedge b) \vee (1-a)$
7) Rs : $a \rightarrow b = \begin{cases} 1 & \cdots\ a \leqq b \\ 0 & \cdots\ a > b \end{cases}$
8) Rg : $a \rightarrow b = \begin{cases} 1 & \cdots\ a \leqq b \\ b & \cdots\ a > b \end{cases}$
9) Rb : $a \rightarrow b = (1-a) \vee b$
10) Rd : $a \rightarrow b = \begin{cases} 1 & \cdots\ a \leqq b \\ b/a & \cdots\ a > b \end{cases}$

Where $R: a \rightarrow b$ is a symbol to represent a fuzzy relation for implication.

③ Set of Unification Method (Step3)

When we set the (a) methods based on fuzzy products in step2, we must select operator of unification in the following six kinds of sum operators.

(a) Sum Operators

1) Logical Sum
2) Averaging Operators of Arithmetic Mean
3) Averaging Operators of Dual of Geometric Mean
4) Averaging Operators of Dual of Harmonic Mean
5) Algebraic Sum
6) Bounded Sum

While, when we set the (b) methods based on implication rules of many valued logic, we must select a operator of unification in the following three kinds of product operators.

(b) Product Operators

1) Logical Product
2) Algebraic Product
3) Bounded Product

④ Set of Linguistic Hedges Method

The linguistic hedges method is to modify the unified fuzzy set by giving a linguistic hedge to it. We can select the following six kinds of linguistic hedges.

1) Concentration
2) Dilation
3) Contrast Intensification
4) Contrast Weakining
5) Slenderizing
6) Swelling

⑤ Set of Defuzzifier Method (Step4)

The simulator has the following two defuzzifier methods obtaining the inference result of the whole rule, and we can select four kinds in each method.

(a) Methods Dealing with the Fuzzy Sets after Unified

1) Center of Gravity Method
2) Average of Maxima Method
3) Midpoint of Maxima Method
4) Midpoint of Area Method

(b) Methods Dealing with each Fuzzy Set before Unified

5) Height Method
6) Maximal Height Method

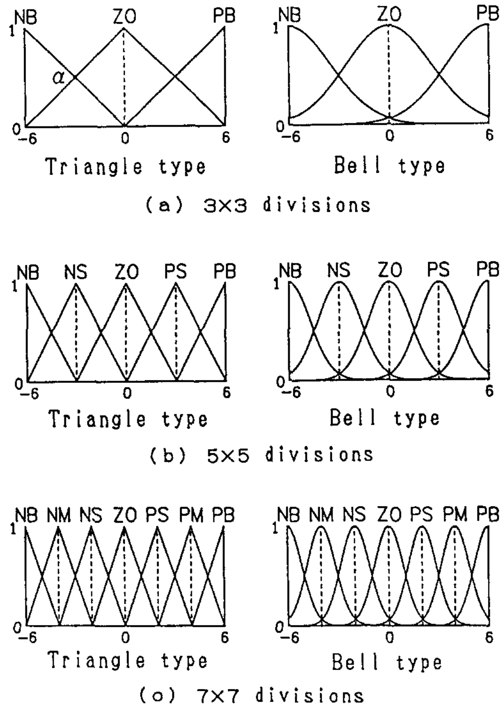

Fig.2 Membership functions for fuzzy labelings.

Table 1 Control rules for fuzzy labelings. (all area type)

3×3 divisions

ΔE \ E	NB	ZO	PB
PB	ZO 1.0	PB 1.0	PB 1.0
ZO	NB 1.0	ZO 1.0	PB 1.0
NB	NB 1.0	NB 1.0	ZO 1.0

5×5 divisions

ΔE \ E	NB	NS	ZO	PS	PB
PB	ZO 1.0	PS 1.0	PB 1.0	PB 1.0	PB 1.0
PS	NS 1.0	ZO 1.0	PS 1.0	PB 1.0	PB 1.0
ZO	NB 1.0	NS 1.0	ZO 1.0	PS 1.0	PB 1.0
NS	NB 1.0	NB 1.0	NS 1.0	ZO 1.0	PS 1.0
NB	NB 1.0	NB 1.0	NB 1.0	NS 1.0	ZO 1.0

7×7 divisions

ΔE \ E	NB	NM	NS	ZO	PS	PM	PB
PB	ZO 1.0	PS 1.0	PM 1.0	PB 1.0	PB 1.0	PB 1.0	PB 1.0
PM	NS 1.0	ZO 1.0	PS 1.0	PM 1.0	PB 1.0	PB 1.0	PB 1.0
PS	NM 1.0	NS 1.0	ZO 1.0	PS 1.0	PM 1.0	PB 1.0	PB 1.0
ZO	NB 1.0	NM 1.0	NS 1.0	ZO 1.0	PS 1.0	PM 1.0	PB 1.0
NS	NB 1.0	NB 1.0	NM 1.0	NS 1.0	ZO 1.0	PS 1.0	PM 1.0
NM	NB 1.0	NB 1.0	NB 1.0	NM 1.0	NS 1.0	ZO 1.0	PS 1.0
NB	NB 1.0	NB 1.0	NB 1.0	NB 1.0	NM 1.0	NS 1.0	ZO 1.0

7) Area Method

8) Maximal Area Method

(4) Set of Membership Functions and Scaling Factors

We can select triangle type and bell type membership functions, and change the degree of their crossing by the set of the crossing value α shown in Fig.2. Also, we can set the scaling factors of the antecedent and consequent parts freely. The crossing value α represents the grade of the point of intersection of neighboring membership functions.

(5) Display of Control Map

By the above procedures, we end the design of a fuzzy controller. The control map of the designed fuzzy controller can be checked in the three dimensional expression on the monitor. Furthermore, we can also check the cross section in case of cutting the control map by a plain.

2.2 EXECUTION PART

(1) Set of Controlled System

The following five cases can be set for a controlled system:

1) Integral System with Dead Time
2) First Order Lag System with Dead Time
3) Second Order Lag System with Dead Time
4) User Entered System
5) Real Controlled System

The block diagram of a fuzzy control system in the simulator is shown in Fig.3. Where E is an error, ΔE is a change in the error, U is a manipulated variable, and ΔU is a change in the manipulated variable. Also, the output of the fuzzy controller is ΔU, and the controller is a velocity type.

(2) Execution of Fuzzy Control

① Monitoring Function

Fig.4 shows an example of display on the monitor for evaluating the control performances in real time simulations. In the display on the monitor, a unified fuzzy set and its defuzzification, matched rules and their weights and matched degrees, a graph of the control response, the selected control method, etc. are described in real time.

② Data Logging Function

The control informations in simulations or actual controls can be logged in a file in real time.

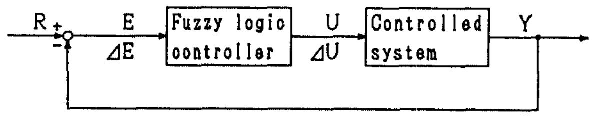

Fig.3 Block diagram of fuzzy control system.

2.3 EVALUATION PART

① Display of Fuzzy Control Result

The logged control informations can be expressed dynamically as error E and manipulated variable U in time domain and the trace on the (E, ΔE) phase plain. The display of a control result is shown in Fig.5.

② Display of Trace of Control Action

The dynamic trace of a control action of a fuzzy controller can be expressed on control map. The display of the trace of a control action is shown in Fig.6.

③ Evaluation Criteria and Functions

For evaluation, the simulator has the following seven criteria for a step response.

1) Overshoot
2) Amplitude
3) Amplitude Damping Ratio
4) Rise Time
5) Reaching Time
6) Overshoot Time
7) Settling Time

Also, the simulator has the function of calculating the following four integral values as the evaluation functions.

1) I.A.E. $\quad : J1 = \int_0^{Ts} |R-Y| dt$

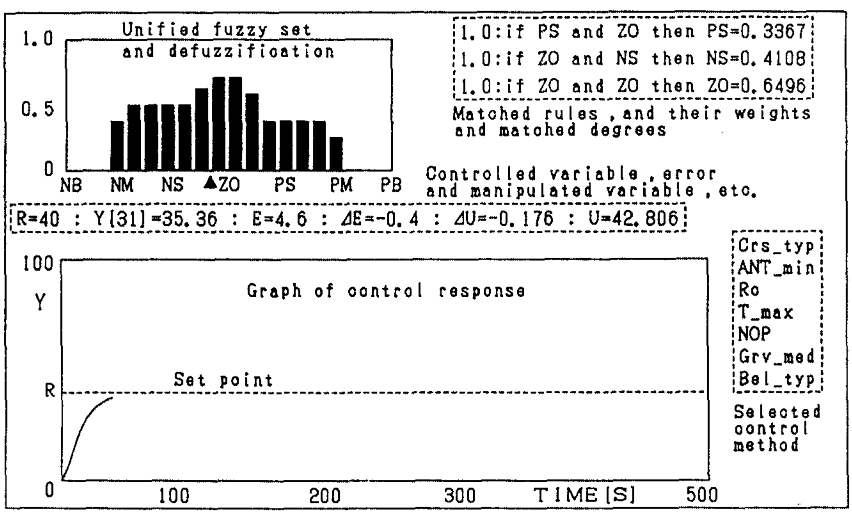

Fig.4 An example of monitoring display.

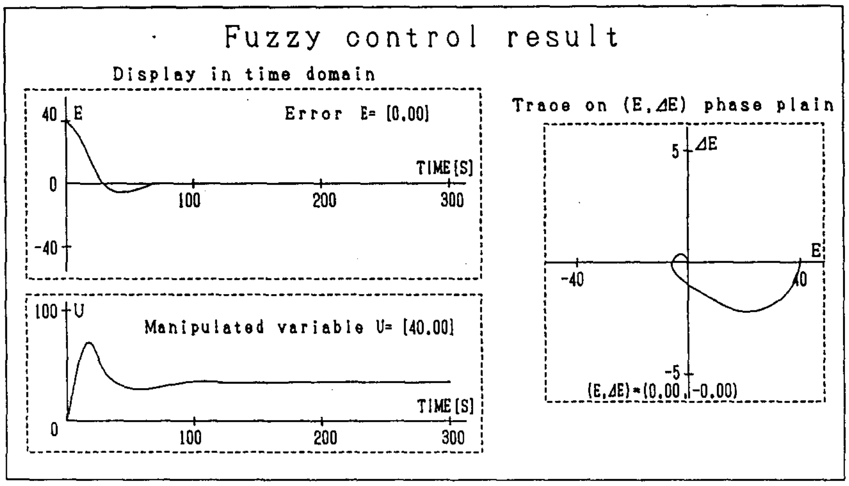

Fig.5 Display of fuzzy control result.

2) I.S.E. : $J2=\int_0^{Ts}(R-Y)^2dt$

3) I.T.A.E. : $J3=\int_0^{Ts}t|R-Y|dt$

4) I.T.S.E. : $J4=\int_0^{Ts}t(R-Y)^2dt$

Where R is a set point, Y is a controlled variable and Ts is a settling time. Also, I.A.E., I.S.E., I.T.A.E. and I.T.S.E. are respectively abbreviations of integral of absolute error, integral of squared error, integral of time multiplied absolute error and integral of time multiplied squared error.

In the simulator, using the seven evaluation criteria and the four evaluation functions mentioned above, we can tune the control parameters of a fuzzy controller and check the control performances easily.

3. CONCLUSION

(1) As the simulator includes several inference methods and so on in each step of fuzzy inference process, we can select the 573 kinds of fuzzy inference methods which have been proposed up to now. Also, we can set control parameters such as control rules, membership functions, scaling factors, etc. freely.
(2) Using the function of simulating fuzzy control systems, we can evaluate the response characteristics

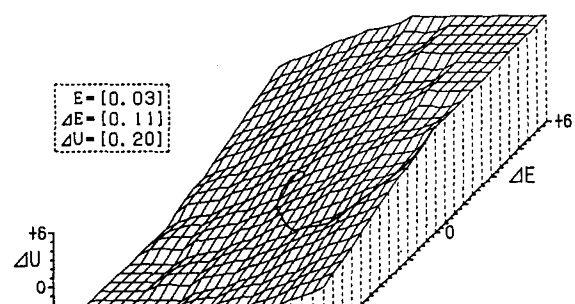

Fig.6 Display of trace of control action on control map.

in a control system, and design the optimum fuzzy controller suited for the controlled system.
(3) As the simulator has a function of evaluating the control performances of the designed fuzzy controller in real time simulations or after simulations, we can execute the work of tuning and inspecting the control parameters efficiently.
(4) The input and output interfaces which can connect the external devices with the simulator can be provided easily, and we can make use of the simulator as a support system for a fuzzy control.
(5) Using the above mentioned functions of the simulator, we can study and design a fuzzy control system very efficiently. As a result, we can obtain new knowledges effective to the design of a fuzzy control system.

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