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퍼지로직제어기를 설계하기 위한 최적 비율 이득 조정방법

An Optimal Scaling Gain Tunig Method for Designing a Fuzzy Logic Controller

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Abstract *This paper propose an optimal scaling gain tuning method of the fuzzy PI controller using Genetic Algorithm(GA). Scaling gains can reflect the control resolution and fuzziness of input/output variables. By the scaling gain method, the design of a fuzzy logic controller(FLC) can be simplified without affecting the system performance in comparison with multi- decision table method. In designing a fuzzy logic controller, the analytic approach method for the optimization is unavailable. Therefore GA is excellent optimization algorithms for scaling gain tuning. Using this optimal scaling gain tuning method, a good performance can be achieved both in transient and steady state.*

Keywords fuzzy PI controller, Genetic Algorithm, scaling gain tuning method

I. Introduction

Fuzzy control was first introduced in the early 1970's[7] in an attempt to design controllers for systems that are structurally difficult to model due to naturally existing nonlinearities and other modeling complexities. During the past years, fuzzy control has emerged as one of the most active and fruitful areas for research in the application of fuzzy set theory[8].

Fuzzy logic control(FLC) appears very useful when the processes are too complex for analysis by conventional quantitative techniques.

Practically, it is also difficult to achieve excellent performance in both the transient and steady state.

Therefore, FLC with scaling gain design and adjustment was proposed[11]. With the scaling gain method, excellent performance in both the transient and steady state can be achieved without using multi-decision tables. So, much of FLC design can be shifted to the design and tuning of scaling gains. In the previous work[11], scaling gains were tuned by off-line trial and error method

To improve the system performance, we propose an optimal gain tuning method using GA. By this method, scaling gains can be optimally adjusted.

II. Fuzzy-PI Control Algorithm

A. Fuzzy-PI Controller with Scaling Gain

A conventional PI control algorithm is:

$$u(t) = K_P e(t) + K_I \int e\ dt \tag{1}$$

In digital implementation, its velocity (incremental) form of the algorithm is used:

$$u_{k+1} = u_k + \Delta u_{k+1}$$
$$\Delta u_{k+1} = K_P \Delta e_k + K_I e_k \tag{2}$$

If e_k and Δe_k are fuzzy variables, (2) becomes a fuzzy control algorithm. Therefore, a practical fuzzy-*PI* control algorithm is extended to (3): F signifies the fuzzy function that acts on the rules given in the form of a look-up table.

$$u_{k+1} = u_k + \Delta u_{k+1} = u_k + K \Delta U_{k+1}$$
$$\Delta U_{k+1} = F\{E_k, \Delta E_k\} = F\{K_I e_k, K_P \Delta e_k\} \tag{3}$$

A practical implementation of Fuzzy PI concept is simplified in Fig. 1.

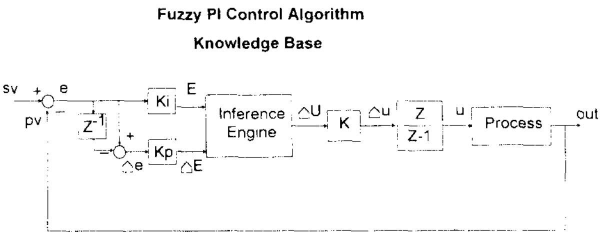


Fig. 1 FLC with PI function

B. Fuzziness and Control Resolution

The control resolution depends on the fuzziness of the control variables, and whereas the fuzziness of control variables depends on the fuzziness of their membership functions.

Fig. 2 shows the equivalence of two fuzzy system. From this relation, we can achieve more fine or more coarse fuzziness with the same membership functions. That is, by adjusting the scaling gain N, a fuzzy variable with coarse Membership Functions(MFs) can achieve the result equivalent to a fuzzy variable with fine MFs as long as their MFs have the same shape, and vice versa. This effect of scaling gain is similarly applicable to the output variable. So, Designing a data base of FLC is to define the fuzziness of the control variables and control resolution. It is equivalent to select the input/output scaling gain K_P, K_I, K in Fig. 1. The tuning of the gains can be guided roughly in Table 1.

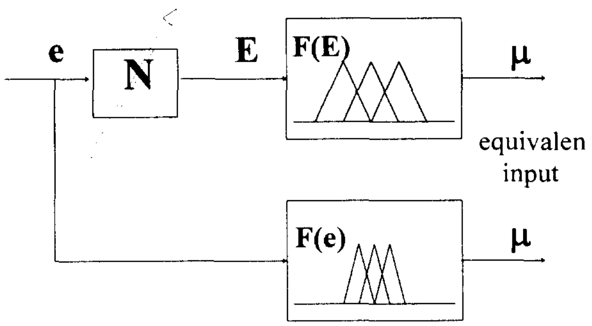


Fig. 2 The effect of scaling gain

Table 1. Tuning Strategy

functions/gain	K_P	K_I	K
coarse tuning	small	small	large
fine tuning	large	large	small

C. FLC Design Procedure

In general, FLC design has two steps as follows.

1. data base design
2. control rule base design

Data base design has the procedure of determination of input/output variables and their membership function. Control rule base design includes the construction of rule base for inference and in this step, the experience of the expert is needed. But, there is no systematic procedure to construct control rule base. Some construction method such as phase diagram method is well known.[] But, so constructed system is not considered to be optimal. But this rule base which is constructed by those method is very useful in GA algorithm for initial state.

In this control scheme, there are some parameters to be tuned for better performance. They are membership functions of variables, rule base, and scaling gains specially in this Fuzzy-PI controller. Fortunately, GA algorithm is very useful in this case that random and global search algorithm is needed. Next, We will describe GA algorithm briefly for your understanding.

III. Optimization Technique

In the previous work[11], 2 sets of the gains were tuned, and according to the predetermined error bound, each gain set was selected and applied to the system. In this case, controller/process switches between two different systems. However, because there is no systematic method for gain tuning, it is very difficult and tedious to get the satisfactory gain set. Therefore, in this paper, we propose optimal scaling gain method by GA.

In our fuzzy system, systematic and analytic methods, which are used in the adaptive control field and neural network, are difficult to be applied because of the complexity and nonlinearity. So, in our case, optimization techniques which can search the optimal values globally are suitable. Among these techniques, GA(Genetic Algorithm) is available for this application[10][11]. The outline of GA is as follows.

GAs

GAs are parallel, global search algorithm based on the mechanics of natural selection and natural genetics[10]. They emulate biological evolution and Darwinian survival of fittest for improving object system's performance.

Procedure of GA

1) Randomly Initialize Parent Population.
2) Evaluate all the member of the parent.
3) Reproduction
4) Crossover
5) Mutation
6) Replace the parent population with the child population
7) if termination criteria is not met goto step 2

IV. Simulation and Result

In Simulation we used the approximated model of thermal process with deadtime in which the process temperature is controlled variable. This plant has 3 deadtime situation in its operation.

$$G(s) = \frac{K}{1+Ts}e^{-Ls} \quad \text{where } T \approx 0.4\,\text{sec} \tag{4}$$

$$L_1 \approx 0.1\,\text{sec} \quad L_2 \approx 0.5\,\text{sec} \quad L_3 \approx 0.8\,\text{sec}$$

At each situation, the effect of deadtime under Fuzzy-PI and conventional PI is compared. FLC and PI are tuned by GA. GA configurations are as follows.

crossover prob.	0.7
mutation prob.	0.1
population size	50
generation	50

Fitness function is defined like (5).

$$\text{Fitness} = \frac{1000.0}{(1+\sum(w_1 ke^2(k) + w_2 k\Delta e^2(k))} \tag{5}$$

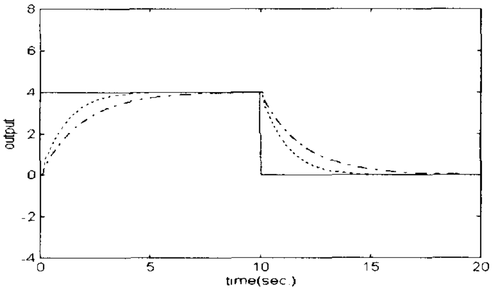
We tuned parameters for mid deadtime and applied these parameters to different deadtime situation. At first PI controller was designed by Ziegler-Nichols method but the performance is not satisfactory compared with that of GA tuned PI, so we select the result of GA tuned PI for the sake of comparison. In FLC, MFs of variable are triangle shape and Rule base are constructed by phase diagram method.

Fig. 3(a),(b),(c) are time response of the plant controlled by FLC and PI with deadtime 0.1, 0.5, and 0.8 respectively. In spite that two controller are similar PI type, the performance of FLC is better. In general PI type has long rise time, fitness function is determined so that response has good transient property. For this purpose we set weight as follows.

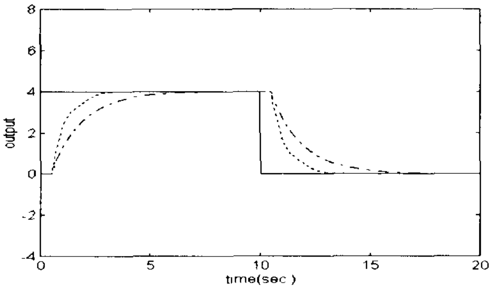
$$w_1 > w_2$$

This term decreases the fitness in proportion to the error, so GA algorithm select parameters which gives larger fitness. That is, the transient performance is get better.

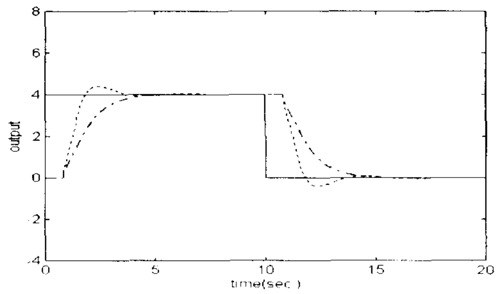
Table 2. shows the result of optimization by GA for FLC and PI controller. The result verifies the concept of fuzziness and control resolution.



(a)



(b)



(c)

Fig. 3. performance of Fuzzy PI and PI control (a) at L_1=0.1sec. (b) at L_2 = 0.5sec (c) at L_3 = 0.5sec. (dahsed dot : PI control, dotted : Fuzzy PI control))

Table 2. Result of GA

Controller / Gain	FLC		PI
	Coarse	Fine	
Kp	3.484	1.485	0.1359
Ki	0.1142	0.08979	0.01059
K	0.07059	0.08077	

V. Conclusion

In this paper, GA is applied to tune the Fuzzy PI controller, therefore it was possible to tune parameters automatically without tedious repeatative trial-error method. Also, among the solutions which is satisfactory in performance we can tune the parameters in desired way by changing the fitness function. We compared Fuzzy PI and conventional PI controller in different deadtime situation through simulation and showed that FLC is satisfactotry in the transient and steady state criterion. In this method, because parameter optimization using GA is performed with the plant model, the accuracy and validity of the tuned parameters depends on the validity of the plant model. Therefore it is necessary to devise a method to tune the parameters of a controller for a partially known or unknown plant.

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