The Third AFSS(1998), 474－478

Design of Fuzzy Scaling Gain Controller using Genetic Algorithm

Hyunseok Shin, Sungryul Lee, Hyungjin Kang, Cheol Kwon, Mignon Park

Dept. of Electronic Engineering, Yonsei University
134, Shinchon-Dong, Sudaemun-ku, Seoul, 120-749, Korea
Tel: +82-2-361-2868, Fax: +82-2-312-4584, E-mail: mignpark@bubble.yonsei.ac.kr

Abstract

This paper proposes a method which can resolve the problem of existing fuzzy PI controller using optimal scaling gains obtained by genetic algorithm. The new method adapt a fuzzy logic controller as a high level controller to perform scaling gain algorithm between two pre-determined sets.

Keywords Fuzzy PI Controller, Genetic Algorithm, Scaling Gain Algorithm

1. Introduction

Fuzzy logic control(FLC) appears very useful when the processes are too complex for analysis by conventional quantitative techniques. But, practically it is so difficult to achieve excellent performance in both the transient and steady state. Therefore, FLC with scaling gain design and adjustment was proposed[2]. 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[1], we proposed an optimal gain tuning method using Genetic algorithm(GA). By this method, scaling gains can be optimally adjusted.

But, switching between two optimal scaling gains can make some problems like chattering. So, we propose new method which performs scaling gain algorithm by another fuzzy controller ,which is actually supervisory controller.

2. Fuzzy PI Controller with Scaling Gain

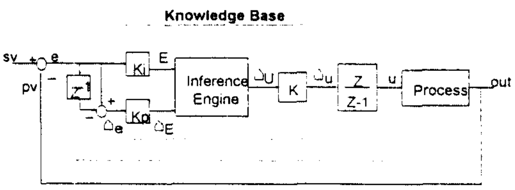

Fig.2-1 Diagram of Fuzzy PI Controller

The general fuzzy PI controller is shown as Fig.2-1.[2]

If we use Ki, Kp, and Ko as scaling gains, many advantages[2]. That is due to the following fact. Changing scaling gain sets means that relating fuzziness of input, output variables with control resolution. And using this fact, we can decide the resolution of controller simply by adjusting scaling gain(Fig.2-2)[2]. In general, the output of a system reaches to steady state passing through transient state. In each state, the different control resolution is required because of the characteristics of each state is different. For example, in transient state, a plant needs coarse and fast control input due to large error. On the other hand, in steady state, fine control input is required to reduce steady state error. Therefore for both control resolution we must construct multi-rule base. But in this case, simply adjusting scaling gain sets we can expect the effect of multi-rule base.

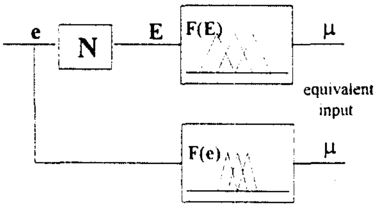

Fig.2-2 Effect of Scaling Gain

3. Fuzzy Scaling Gain Algorithm

In previous work[1], there are some problems. For

Example, scaling gain sets cannot be considered to be optimal when using these gain sets for the intermediate state which was not tuned by GA. Also when switching between these two sets, noise and chattering can be generated especially when controlling nonlinear plant.

So, this paper propose a method which interpolates two scaling gain sets by fuzzy inference instead of switching gain sets(Fig.3-1). This method resolves the problems mentioned above and can easily reflect the experience of expert. And, the performance of the proposed method is verified by computer simulation for both linear and nonlinear plant.

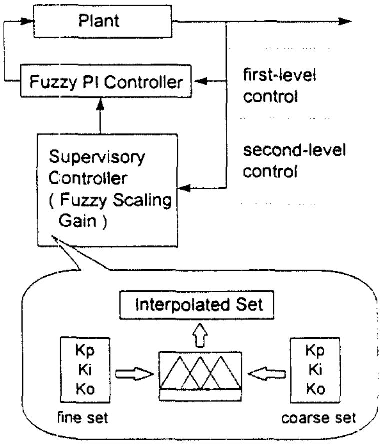

Fig.3-1 Diagram of Fuzzy Scaling Gain Controller

Also, Fig.3-2 shows the tuning strategy to obtain optimal scaling gain sets.

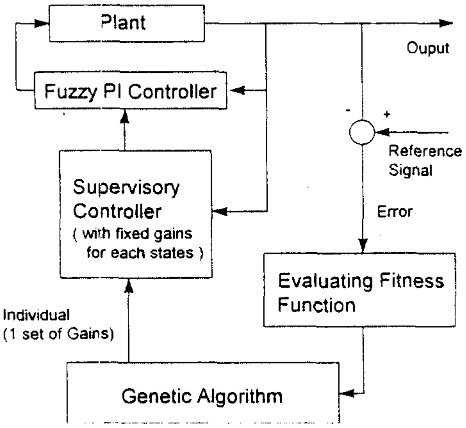

Fig.3-2 Searching for optimal gain sets using GA

4. Simulations and Results

In this simulation, a simple linear plant, and a complex nonlinear plant is considered. For each plant, GA can find optimal scaling gain sets. And, to compare each scaling gain set's characteristics, the simulation of each plant is composed of the following 4 cases.

case 1. Simulation with only transient state scaling gain set.

case 2. Simulation with only steady state scaling gain set.

case 3. Simulation with previous fuzzy PI controller using scaling gain sets.

case 4. Simulation with fuzzy scaling gain controller.

4.1 Simulation with a Linear System

The first simulation is performed for a simple linear plant(Eq.4-1).

$$G(s) = \frac{s+1}{s^2+4s+5} \qquad \text{(Eq.4-1)}$$

And, the parameters of GA are given in Table 4-1. ω_1 and ω_2 are adjusting weights for matching priorities of error and differential error.

Table 4-1 Parameter of GA

Population size	50
Maximum Generation	50
Mutation Rate	0.1
Crossover Rate	0.7
Fitness Function	$\frac{1}{1+w_1E^2+w_2\dot{E}^2}$

The results after some GA computation is shown in Table 4-2.

Table 4-2 Gain Sets obtained by GA

		Gain Sets
Transient State	Kp	0.06451612903226
	Ki	1.85043988269795
	Ko	0.55816226783969
Steady State	Kp	0.14271749755621
	Ki	1.21603128054741
	Ko	0.97067448680352

The following graphs shows the effectiveness of the proposed method.

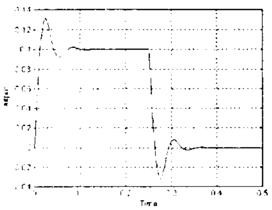

Fig.4-1 (1) Output
(using only transient state gains)

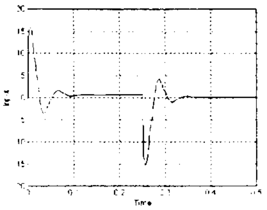

Fig.4-1 (2) Input
(using only transient state gains)

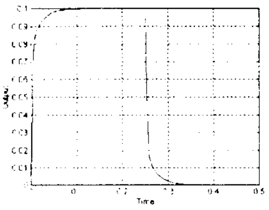

Fig.4-2 (1) Output
(using only steady state gains)

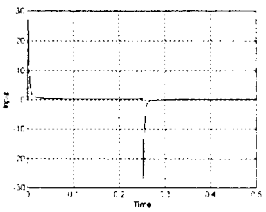

Fig.4-2 (2) Input
(using only steady state gains)

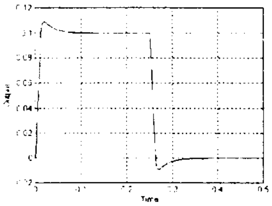

Fig.4-3 (1) Output
(using scaling gain algorithm)

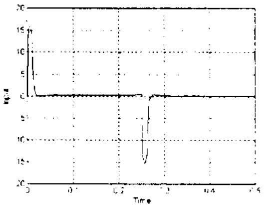

Fig.4-3 (2) Input
(using scaling gain algorithm)

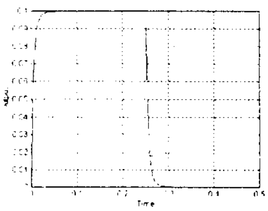

Fig.4-4 (1) Output
(using proposed method)

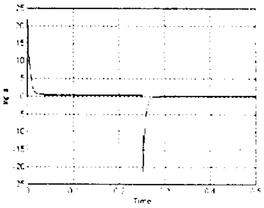

Fig.4-4 (2) Input
(using proposed method)

For comparison, some measure are shown in Table 4-3.

Table 4-3 Comparison of each case

	Rising Time (sec)	Percent Overshoot (%)	Settling Time (Sec)
case 1	0.010	32.0	0.064
case 2	0.015	0	0.032
case 3	0.009	9.2	0.036
case 4	0.011	0	0.018

In the case 1, the output of plant shows large overshoot and oscillation(Fig.4-1), and in the case 2, the convergence speed is too slow(Fig.4-2). Therefore, using scaling gain algorithm according to error and differential error of plant gives better result mixing each scaling gain set's merit, but still unsatisfactory(Fig.4-3). The result of the proposed method gives the best performance(Fig.4-4, Table 4-3).

4.2 Simulation with a Nonlinear System

Rotational inverted pendulum(Fig.4-5) was used for 2nd simulation[8]. As widely known, rotational inverted pendulum is heavily nonlinear plant, analysis of which is quite complex.

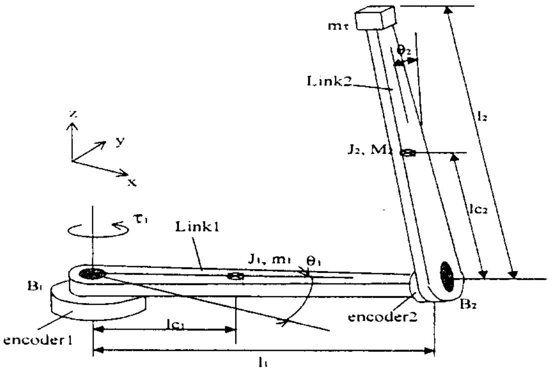

Fig.4-5 Rotational Inverted Pendulum

The dynamic equation of rotational inverted pendulum is as follows(Eq. 4-2)[8].

$$\begin{aligned}&(J_1 + M_e l_1^2 + ML_e^2 \sin\theta_2)\ddot{\theta}_1 - l_1 ML_e \cos\theta_2 \ddot{\theta}_2 \\ &+ (B_1 + ML_e^2 \sin 2\theta_2 \dot{\theta}_2)\dot{\theta}_1 + l_1 ML_e \sin\theta_2 \dot{\theta}_2^2 = \tau \\ &l_1 ML_e \cos\theta_2 \ddot{\theta}_1 - (J_2 + ML_e^2)\ddot{\theta}_2 + ML_e g \sin\theta_2 \\ &+ ML_e^2 \sin 2\theta_2 \cos\theta_2 \dot{\theta}_1^2 - B_2 \dot{\theta}_2 = 0\end{aligned} \qquad \text{(Eq.4-2)}$$

$$(M_e = m_2 + m_T,\ ML_e = m_2 l_{c2} + m_T l_2,\ ML_e^2 = m_2 l_{c2}^2 + m_T l_2^2)$$

For simulation, we set the variables of rotational inverted pendulum as in Table 4-4.

Table 4-4 Constants of Rotational Inverted Pendulum

l_1	0.22m	J_2	1.98×10^{-4}kg · m²
l_2	0.12m	B_1	0.118N · m · s
m_2	0.055kg	B_2	8.3×10^{-3}N · m · s
J_1	0.0175kg · m²	l_{c2}	0.06m

After some calculation of GA, optimal scaling gain sets were obtained as in Table 4-5.

Table 4-5 Optimal Gain sets obtained by GA

		Gain Value
Transient State	Kp	0.70869990224829
	Ki	0.41231671554252
	Ko	0.3264907135875
Steady State	Kp	0.78592375366569
	Ki	0.22228739002933
	Ko	0.5591397849462

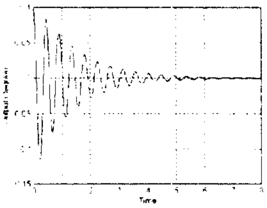

Fig.4-6 (1) Output
(using only transient state gains when error is small)

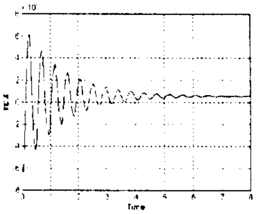

Fig.4-6 (2) Input
(using only transient state gains when error is small)

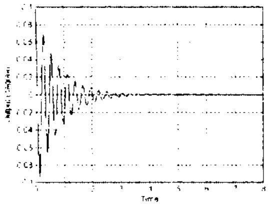

Fig.4-7 (1) Output
(using only steady state gains when error is small)

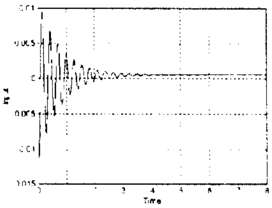

Fig.4-7 (2) Input
(using only steady state gains when error is small)

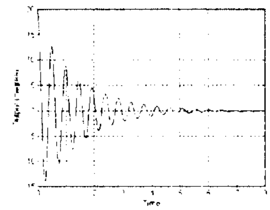

Fig.4-8 (1) Output
(using only transient state gains when error is big)

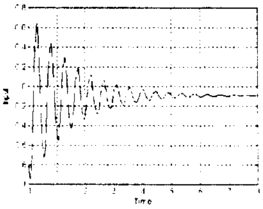

Fig.4-8 (2) Input
(using only transient state gains when error is big)

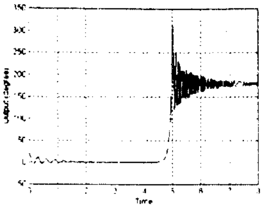

Fig.4-9 (1) Output
(using only steady state gains when error is big)

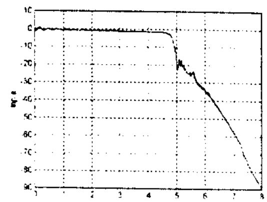

Fig.4-9 (2) Input
(using only steady state gains when error is big)

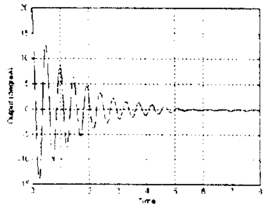

Fig.4-10 (1) Output
(using scaling gain algorithm)

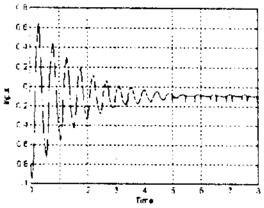

Fig.4-10 (2) Input
(using scaling gain algorithm)

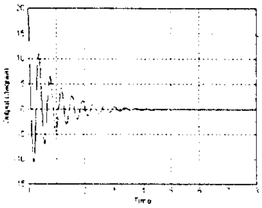

Fig.4-11 (1) Output
(using proposed method)

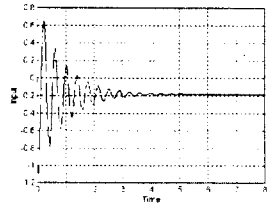

Fig.4-11 (2) Input
(using proposed method)

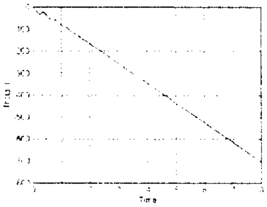

Fig.4-11 (3) θ_1
(using proposed method)

For comparison, the value of measurement are arranged as follows(Table 4-6).

Table 4-6 Comparison of each case

		Settling Time (sec)	Sum of Error
when error is small	*case 1*	4.32	0.0783
	case 2	2.41	0.0716
when error is big	*case 1*	4.02	2.1769×10^3
	case 2	Divergence	8.1982×10^5
case 3		4.23	2.1765×10^3
case 4		2.35	1.8481×10^3

$$* \text{Sum of Error} = 100 \times e^2 + \dot{e}^2$$

To verify the each gain set's role, the simulation is divided to some phase. When the error is small(Initial error : 0.01'), the steady state scaling gain set gives better performance as shown in Fig.4-6 and fig.4-7. But, this steady state scaling gain set can not control the output of plant when error is big(Initial error : 20') and the pendulum was down(Fig.4-9). To the contrary, the transient scaling gain set can manage to set the pendulum(Fig.4-10).

When using scaling gain algorithm for this plant, the output looks being converged. But, the plant output is continuously oscillating to some extent(Fig.4-12). This is due to the fact that at the point of changing two different scaling gain sets, the input generated by controller shows the chattering.

But, since the proposed method generates the input without switching, the plant output is smooth, and shows fast convergence.

5. Conclusion

In this paper, we've observed that the proposed fuzzy scaling gain controller can solve the problems of previous fuzzy PI controller. By several simulation applying to a linear and a nonlinear plant, the proposed method was proved to be valid.

But, this method needs some modification. In Fig.4-11 (3), θ_1 is diverging, and this means that the rotational inverted pendulum is continuously moving with uniform velocity. This is due to the fact that the controller used in this simulation consider only θ_2, and $\dot{\theta}_2$. So, if desiring to set θ_2 to hold on any position, the controller must be reconstructed to be capable of receiving additional information of θ_1.

Also, this method can be expanded to use multi point scaling gain sets. In other words, in this paper, only two gain sets are used. But if we define more point, GA will find more optimal scaling gain sets, and the performance of controller will be enhanced.

6. References

[1] Hyunseok Shin, Hansoo Shim, Cheol Kwon, Hyungjin Kang, Mignon park, "Designing a Fuzzy Logic Controller Using GA Optimal scaling Gain Tuning Method," Proceedings of JCEANF '96 pp 23-26, 1996

[2] Han-Xiong Li and H. B. Gatland, "A New Methodology for Designing a Fuzzy Logic Controller," IEEE Trans. Syst. Man Cyber., vol 25, no. 3, pp 505-512, March 1995

[3] Jianzhou WANG, Jim R. JORDAN, "Auto-Tuning Algorithm For Fuzzy Control Systems," 7th IFSA World Congress, Prague. pp 517-525, 1997

[4] G. M. Abdelnour, "Designing of a fuzzy controller using input and output mapping factors," IEEE Trans. Syst. Man Cyber., vol. 21, no.5, pp 952-960, Sept 1991

[5] D. E. Goldberg, "Genetic Algorithms in Search, Optimization, and Machine Learning," Addison-Wesley, Reading, MA. 1989

[6] M. A. Lee, H. Takagi, "Integrating Design Stages of Fuzzy Systems using Genetic Algorithms," IEEE Fuzz. pp 612-617, 1993

[7] Li-Xin Wang, *A Course in Fuzzy Systems and Control*, Prentice Hall, pp 249-264, 277-288, 1997

[8] Y. K. Ha and A. Tomizuka, "Fuzzy Global and Local Motion Control of an Inverted Pendulum Using Multiple Rule Bases," Proc. of Asian Control Conf., July, pp 27-30,1994