International Conference on Control, Automation and Systems 2008
Oct. 14-17, 2008 in COEX, Seoul, Korea

Development of PSO-based PID Tuning Method

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Abstract: This paper proposes a new PID parameter tuning method using Particle Swarm Optimization (PSO) without tuning operator's know-how. The method searches the PID parameter that realizes the expected step response of the plant. The expected response is defined by the overshoot ratio, the rising time, the settling time. The method is implemented into the PID tuning tool on a personal computer. The plant model represented by the transfer function is obtained by system identification on the PID tuning tool. The PID parameter is computed by PSO-based PID tuning method according to the obtained model. The numerical result and the experiment result show the effectiveness of the proposed tuning method and the developed tool.

Keywords: PID Control, Particle Swarm Optimization, System Identification.

1. INTRODUCTION

PID control is a generic feedback control technology and it makes up 90% of automatic controllers in industrial control systems [1]. The PID control has played an important role for the total energy saving system to operate each single loop control system appropriately.

For a satisfied control performance by the PID control system, an appropriate PID parameter tuning is necessary [1]. In fact, PID parameter tuning depends on operator's know-how, therefore a PID parameter has not been frequently optimal from the viewpoint of qualities.

Ziegler Nichols tuning rule or CHR (Chien-Hrones-Reswick) tuning rule has been applied to the PID tuning frequently [2]. These methods are for the basic PID controller. Therefore, these are not optimal for the practical controller such as PI-D or I-PD controllers including nonlinear characteristics. The tuning method based on PSO (Particle Swarm Optimization) [3] has already been proposed to obtain the optimal PID parameter [4]. This method has not considered the step response of constraints (the overshoot ratio, the rising time, the settling time and so on). This paper presents a new method that obtains the PID parameter realizing the expected step response with the constraints.

A proposed method using Particle Swarm Optimization (PSO) is implemented into the PID tuning tool on a personal computer. The developed tool provides the PID parameter that realizes the expected step response of the plant. The numerical result and the experimental result show the effectiveness of the proposed a new PID parameter tuning method.

2. SUMMARY OF THE PID TUNING TOOL

A new PID tuning method needs the plant model of the controlled object in advance, thus it needs system identification to obtain the plant process model. Therefore, the procedure of system identification and the PID tuning is implemented as PID tuning tool on a personal computer. On the tool, the plant model represented by the transfer function is obtained by system identification. And based on the model, PID parameter is obtained by PSO-based PID tuning method. This PID tuning tool has following features.

・System identification by start-up or step response data in operation (under the identifiable condition).

・The PID parameter that realizes desirable process value (PV) response is obtained by PSO.

・The PID parameter tuning that has depended on a operator's know-how is automated.

3. SYSTEM IDENTIFICATION

System identification is conducted with data of process value (PV) and manipulated value (MV). The gain, the time constant, and the delay time of the transfer function that defined by the user in advance are obtained. The constructions of the transfer function are prepared, for example, as Table 1. Where G is the process gain, T, T_1, T_2 are the time constant, L is the time delay on the transfer function on Table 1. The constructions of the transfer function are able to be customized with user need.

System identification is based on the optimization that minimizes the objective function. The objective function J is defined as integral square error as follows.

$$J = \int_0^T (\hat{P}V(\rho) - PV)^2 \, dt \qquad (1)$$

Table 1. A configuration diagram of FePIDtune.

Type of transfer function	Transfer function
First order with time lag	$\frac{G}{1+Ts}e^{-Ls}$
Second order with time lag	$\frac{G}{(1+T_1 s)(1+T_2 s)}e^{-Ls}$
First order with integral and time lag	$\frac{G}{s(1+Ts)}e^{-Ls}$

where J is the object function, ρ is the parameter of the transfer function (the objective valuables), T is the evaluate period, ^ is the estimate value computed by the plant simulator in the case of the parameter ρ.

For obtaining the parameter ρ that minimizes Eq. (1), Newton-Raphson method is applied as follows.

$$\hat{\rho}^{(i+1)} = \hat{\rho}^{(i)} - \mu[H(\hat{\rho}^{(i)})]^{-1}\nabla J(\hat{\rho}^{(i)}) \qquad (2)$$

where i is the iteration number, μ is the step length, ∇J is the gradient of J, H is the Hessian of J.

From Eq. (1-2), the parameter ρ of the transfer function is obtained.

4. CONVENTIONAL PID TUNING

The PID tuning tool has two selectable features on the PID tuning phase. One is the conventional PID tuning rules from the formulation on the process model, another is the PID optimal tuning based on PSO. The results of the PID tuning parameter and simulation data are displayed on the PC screen, and the operator is able to check the results.

On the PID tuning tool, the conventional rules of PID tuning are available. The PID parameter is obtained by these rules on the plant model computed by system identification. Available tuning rules are as follows [2].

- Zigler-Nichols tuning rule
- CHR tuning rule
- Cohen-Coon tuning rule

5. PARTICLE SWARM OPTIMIZATION (PSO)

PSO is one of the evolutionary computation methods to solve optimization problems. The method can be applied to non-linear optimization problem that includes constraints without the graduate of the objective function. The procedure of PSO is to iterate the following equation.

$$\begin{aligned} v_{ij}^{(k+1)} &= w \times v_{ij}^{(k)} \\ &\quad + c_1 \times rand() \times (pbest_{ij} - x_{ij}^{(k)}) \\ &\quad + c_2 \times rand() \times (gbest_j - x_{ij}^{(k)}) \end{aligned} \qquad (3)$$

$$x_{ij}^{(k+1)} = x_{ij}^{(k)} + v_{ij}^{(k+1)} \qquad (4)$$

where i is a particle number, j is the PID parameter number, k is a iteration number, x is the PID parameter, v is a moving vector, *pbest* is a personal best of particle i, *gbest* is a global best of all particles, w, $c1$ and $c2$ are weight parameters, *rand*( ) is a uniform random number from 0 to 1.

6. PID OPTIMAL TUNING METHOD OF PID PARAMETER

The conventional tuning rules need trial and error on the experiment or the simulation in order to adjust PV to expected PV. The procedure has depended on the user know-how and has had issue of the tuning cost and period. For the resolution of these problems, the PID optimal tuning method based on PSO is developed. The proposed method computes the PID parameter that realizes expected PV without the user know-how. The concept of the proposal method is shown in Fig. 1.

The response is defined by overshoot ratio, rising time, settling time and so on. The method minimizes the objective function composed by the objective valuables that is the PID parameter.

The objective function f is defined as integral square error as follows.

$$F = \int e(t)^2 \, dt \qquad (5)$$

where $e(t)$ is an error of set point value (SV) and PV.

The constraints are as follows.

$$\begin{aligned} &T_r^L \le T_r \le T_r^U, \ T_d^L \le T_d \le T_d^U \\ &p_0^L \le p_0 \le p_0^U, \ T_p^L \le T_p \le T_p^U \\ &T_s^L \le T_s \le T_s^U, \ E_s^L \le E_s \le E_s^U \end{aligned} \qquad (6)$$

where T_r is a rising time, T_d is a delay time, p_o is an overshoot ratio, T_p is a peak time, T_s is a settling time, E_s is a steady state error, L is lower bound, U is upper bound. The objective valuables (the PID parameter) that minimize the objective function under the constraints are computed by PSO.

7. PID SIMULATOR

Various tuning rules have been proposed such as Ziegler Nichols rule or CHR rule and so on. However, these methods assume the basic PID control not such as I-PD control and IP-D control as shown in Fig.2, where K_p is the proportional gain, T_I is the integral time, T_d is the derivative time, μ is the derivative constant. And conventional rules don't regard non-linear characteristics of the actual controller, for example, MV limiter or integral cut action. On most controllers in the field, the I-PD or the IP-D control is applied including

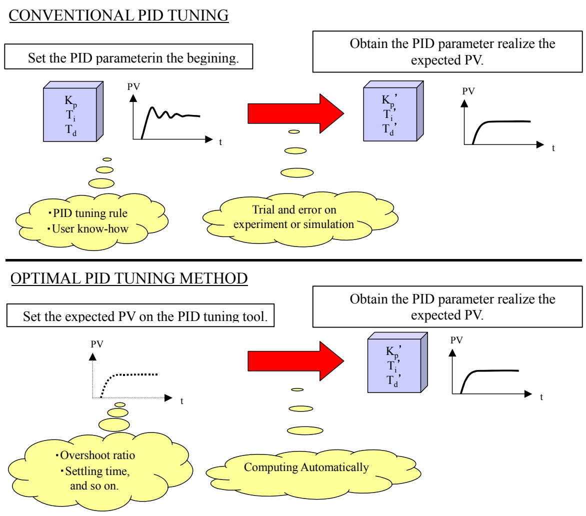

Fig. 1. Concept of the PID proposed method

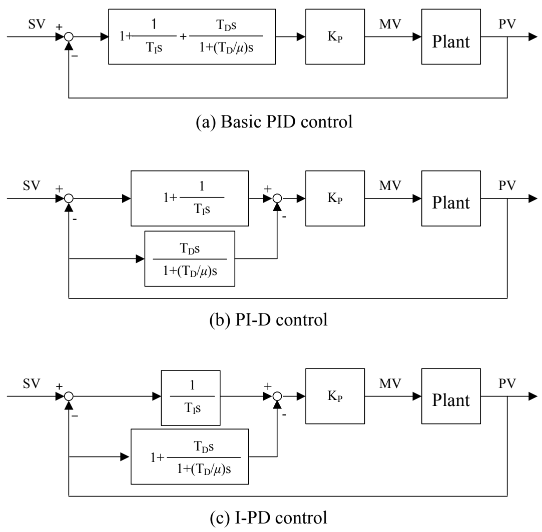

Fig. 2. Block diagram of PID controls.

MV limiter, integral cut action, or any functions including non-liner characteristics. The PID tuning tool is able to reflect these features of the real controller by using the PID simulator reacting the real controller. The PID tuning method based on PSO uses the PID simulator to obtain the evaluate value of J, Eq (3).

8. NUMERICAL RESULT AND EXPERIMENTAL RESULT

For the purpose of showing the effectiveness of the proposed method and the developed tool, numerical examples and experimental examples are studied. In the examples, the developed PID tuning tool is applied to the closed loop system that is composed by the PID controller and the plant.

8.1 Numerical Result

The defined plant model $P(s)$ by the transfer function is as follows.

$$P(s) = \frac{10}{(1+8.0s)(1+2.0s)} e^{-1.0s} \tag{7}$$

In this numerical example, the PID controller is designed as the basic PID control, Fig. 2-(a).

Based on the plant model, the optimal PID tuning method is applied. The expected PV responses are shown in Table 2. As a result of PID parameter tuning, the PID parameter of the traditional tuning (e.g. CHR tuning) and the proposed method are shown in Table 3, PV data are shown in Fig.3, evaluation of PV data are shown in Table 4. In this example, in order to apply CHR tuning to this problem, two time constants are considered as one time constant. According to the results, it is observed that the proposed method is able to obtain the desirable PID parameter under constraints against CHR tuning.

8.2 Experimental Result

For the experimental example, the PID tuning tool including proposed PID tuning method is applied to the thermal control. The diagram of the thermal control system is shown in Fig.4. In this experimental example, the PID controller is designed as the PI-D control, Fig. 2-(b), and it has a MV limiter (-3.0≦MV≦103.0).

For the PID tuning, the system identification is conducted on the PID tuning tool for the obtaining the plant model. The identification data is shown in Fig.5 and Fig.6. As a result of the identification, the plant model is obtained as follows.

$$P(s) = \frac{0.69}{1+24.91s} e^{-5.75s} \tag{8}$$

Based on the obtained model, the proposed PID tuning method is applied to the thermal control system. The expected PV responses are shown in Table 5. As a result of PID parameter tuning, the PID parameter of the traditional method (e.g. CHR rule) and the proposed method are shown in Table 6, PV data are shown in Fig.7, MV data are shown in Fig.8, evaluation of PV data are shown in Table 7. According to the results, it is observed that the proposed method is able to obtain the desirable PID parameter under constraints against CHR tuning.

Table 2. Constraints for the proposed method.

Evaluation of PV data	Constraint
T_r: Rising time[sec]	$1.0 \leqq T_r \leqq 5.0$
T_s: Settling time[sec]	$20.0 \leqq T_s \leqq 30.0$
p_0: Overshoot ratio[%]	$0.0 \leqq p_0 \leqq 5.0$
E_s: Steady state error[%]	$0.0 \leqq E_s \leqq 0.1$

Table 3. Results of the CHR tuning and proposed method.

PID parameter	CHR tuning	Proposed method
Proportional gain	0.60	0.44
Integral time [sec]	10.0	17.4
Derivative time [sec]	0.5	1.0

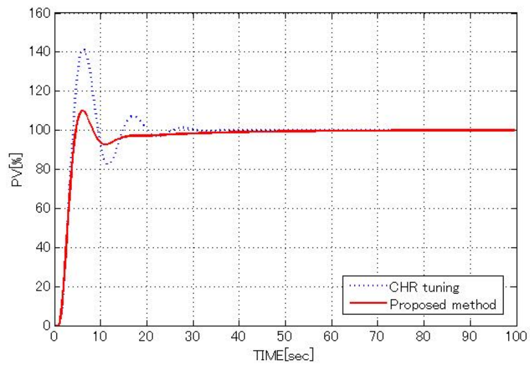

Fig.3. PV data of the CHR tuning and the proposed method.

Table 4. Results of the CHR tuning and the proposed method.

Evaluation of PV data	CHR tuning	Proposed method
T_r: Rising time[sec]	2.1	3.3
T_s: Settling time[sec]	24.0	29.9
p_0: Overshoot ratio[%]	41.7	4.9
E_s: Steady state error[%]	0.0	0.0

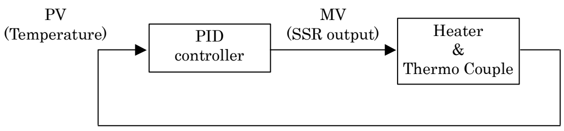

Fig. 4. Diagram of the thermal control system.

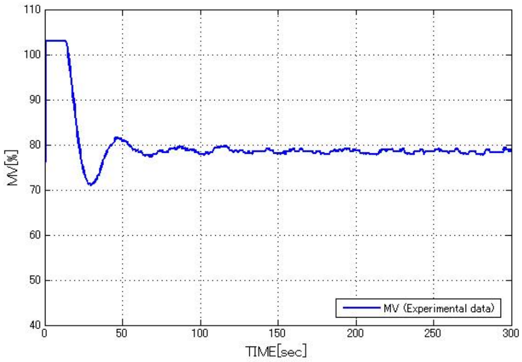

Fig.5 MV data for the identification.

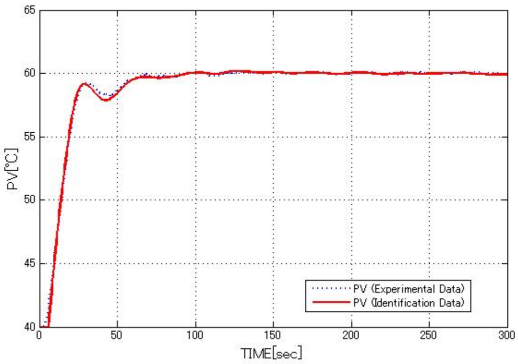

Fig.6 PV data and identification result.

Table 5. Constraints for the proposed method.

Evaluation of PV data	Constraint
T_r: Rising time[sec]	$20.0 \leqq T_r \leqq 30.0$
T_s: Settling time[sec]	$30.0 \leqq T_s \leqq 40.0$
p_0: Overshoot ratio[%]	$0.0 \leqq p_0 \leqq 1.0$
E_s: Steady state error[%]	$0.0 \leqq E_s \leqq 0.1$

Table 6. Results of the CHR tuning and the proposed method.

PID parameter	CHR tuning	Proposed method
Proportional gain	3.76	2.10
Integral time [sec]	29.9	23.6
Derivative time [sec]	2.9	0.4

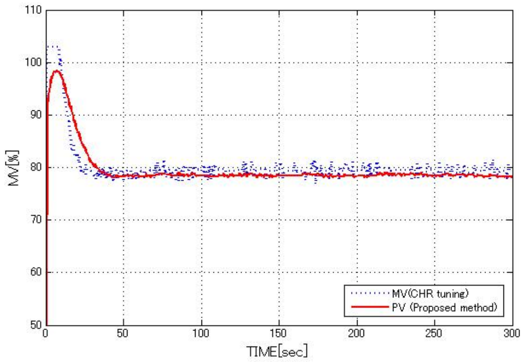

Fig.7. MV data of the CHR tuning and the proposed method

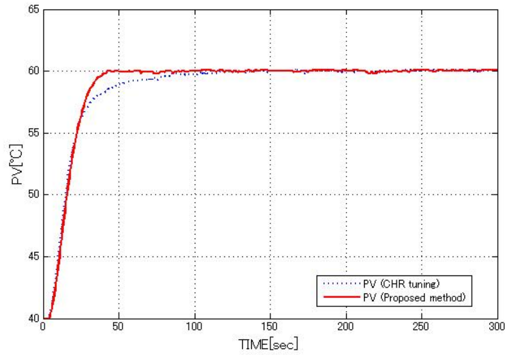

Fig.8. PV data of the CHR tuning and the proposed method

Table 7. Results of the CHR tuning and the proposed method.

Evaluation of PV data	CHR tuning	Proposed method
T_r: Rising time[sec]	30.0	21.5
T_s: Settling time[sec]	52.5	33.0
p_0: Overshoot ratio[%]	0.5	0.5
E_s: Steady state error[%]	0.1	0.1

9. CONCLUSIONS

This paper presents a new method that obtains the PID parameter realizing the expected step response with the constraints. The proposed method is implemented into the PID tuning tool on a personal computer. The developed tool provides the PID parameter that realizes the expected step response of the plant. The numerical result and the experimental result show the effectiveness of the proposed PSO-based PID tuning method.

Future work is to develop the method to obtain the optimal PID parameter to disturbance.

REFERENCES

[1] Carl Knospe: "PID Control", IEEE Control Magazine, pp.30-31, 2006.
[2] Karl J. Astrom and Tore Hagglund: "PID Controllers: Theory, Design, and Tuning ", International Society for Measurement and Con, 1995.
[3] J.Kennedy, R.C.Eberhart: "Swarm Intelligence", Morgan Kaufmann Publishers, 2001.
[4] Z.L.Gaing, "A Particle Swarm Optimization Approach For Optimum Design of PID Controller in AVR system", IEEE Trans. on Energy Conversion, Vol.19, No.2, pp.384-391