

Design of local linear models using Self tuning Control System for PID Tuning According to error

Shinichi Imai*

Graduate school, Tokyo Gakugei University,
4-1-1, Nukuikita-machi, Koganei, Tokyo, 184-8501, Japan.

E-mail: shimai@u-gakugei.ac.jp
<http://www.u-gakugei.ac.jp/>[†]

Abstract

PID control is widely used in process systems represented by chemical processes and petroleum refining processes. The reason is that PID control has a simple structure. However, most of the existing systems are non-linear systems, and it is difficult to always obtain good control results with fixed PID control. Therefore, in this study, we propose a method of tuning the PID gain according to the deviation (control error) of the control result, and verify the effectiveness of this method through experiments. For self-tuning PID control using a local linear model, we propose a program that performs PID tuning only when the deviation occurs with a certain magnitude. A simulation is performed on the Hammerstein model, which is a non-linear system. As a result of the experiment, the number of PID gain changes could be significantly reduced.

Keywords: Local Linear Models, PID controller, Control error.

1. Introduction

PID control [1,2] is widely used in industry, especially in process systems such as chemical processes and oil refining processes. PID control is widely used in industry, especially in process systems such as chemical and oil refining processes. However, the characteristics of many real systems vary according to environmental and operating conditions, and they include nonlinear systems. Therefore, it is difficult to obtain good control results with fixed PID control. For this reason, methods using machine learning and data-driven control [3,4] have been proposed as effective control methods for nonlinear systems. However, since these methods perform PID tuning at each step, the computational processing load is

large, and only high-precision computers can handle them.

In this paper, we propose a method to tune the PID gain only when the control result does not follow the target value. In this method, a threshold value is set for the deviation, and PID control is performed only when the threshold value is exceeded. If the deviation is smaller than the threshold, the PID gain is not changed. Simulation is performed on a bilinear model, which is a nonlinear system, to verify the effectiveness of this method in reducing the computational load and focusing on the control results. A method of tuning the PID gain according to the deviation of the control results (control error) is proposed, and the effectiveness of this method is verified through numerical examples.

2. A design of a self-tuning control system using a local linear model that performs PID tuning according to deviation

The block diagram of the proposed control system is shown in Fig. 1. The authors have previously proposed a method for calculating control parameters using the idea of the local linear model method [5]. This method can be used to control a nonlinear system by creating a locally linear model. In the proposed control method, the deviation is evaluated for a self-tuning control system using a local linear model.

2.1. System description

First, consider the discrete-time nonlinear system represented by

$$y(t) = f(\varphi(t - 1)) \tag{1}$$

where, $y(t)$ represents the system output and $f(\cdot)$ represents the nonlinear function. Also, $\varphi(t-1)$ represents the state of the system before time $t-1$ (historical data) and is called the information vector. The information vector $\varphi(t-1)$ is defined by the following equation.

$$\varphi(t - 1) := [y(t - 1), y(t - 2), \dots, y(t - n_y), u(t - 1), u(t - 2), \dots, u(t - n_u)] \tag{2}$$

Furthermore, $u(t)$ is the control input, and n_y and n_u are the orders of the output and input, respectively. Now, suppose that the nonlinear system represented by equation (1) can be locally represented by a linear model as follows

$$A_i(z^{-1})y(t) = z^{-(k_m+1)}B_i(z^{-1})u(t) \tag{3}$$

(i = 1, 2, ..., N)

where, in Eq. (3), k_m represents the minimum estimate of the lag time, and when the lag time is known, k_m is set to that value; when the range of the lag time is unknown, k_m is set to 0. Furthermore, z^{-1} represents a time-delay operator, meaning $z^{-1}y(t) = y(t - 1)$. Also, $A(z^{-1})$ and $B(z^{-1})$ are given by

$$A_i(z^{-1}) = 1 + a_{i,1}z^{-1} + \dots + a_{i,n_y}z^{-n_y} \tag{4}$$

$$B_i(z^{-1}) = b_0 + b_{i,1}z^{-1} + \dots + b_{i,n_u}z^{-n_u} \tag{5}$$

After the above preparation, the controller is designed for the local linear model.

2.2. Controller Design

Design the controller based on the following steps.

[STEP1] Construction of multiple linear models

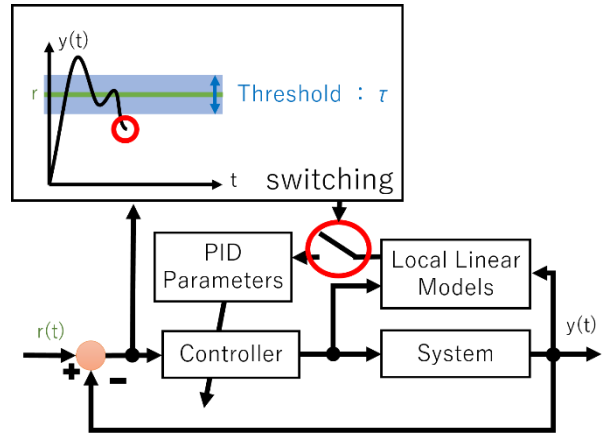


Fig. 1. Block diagram

For the nonlinear model, multiple linear models are constructed, system identification is performed using the lumped least squares method, and the parameters of $A_i(z - 1)$ and $B_i(z - 1)$ ($i = 1, 2, \dots, N$; where i takes these values unless otherwise noted) included in the linear model of Eq. (3) are estimated.) parameters in the linear model.

[STEP2] Design of control system

For the linear model represented by Eq. (3), consider the feedback control law given by Eq.

$$R(z^{-1})y(t) + S(z^{-1})\Delta u(t) - R(1)r(t) = 0 \tag{6}$$

where, $r(t)$ represents the target value at step t . $R(z^{-1})$ and $S(z^{-1})$ are polynomials designed based on the pole configuration of the closed-loop system, respectively.

$$\left. \begin{aligned} R_i(z^{-1}) &= r_{i,0} + r_{i,1}z^{-1} + \dots + r_{i,n_1}z^{-n_1} \\ S_i(z^{-1}) &= 1 + s_{i,1}z^{-1} + \dots + s_{i,n_2}z^{-n_2} \end{aligned} \right\} \tag{7}$$

$R(z^{-1})$ and $S(z^{-1})$ are designed based on the pole placement method. In this case, the input-output relation of the closed-loop system composed of equations (3) and (6) is expressed by the following Eq.

$$y_i(t) = \frac{z^{-(k_m+1)}B_i(z^{-1})R_i(1)}{P(z^{-1})}r(t) \tag{8}$$

The denominator polynomial $P(z^{-1})$ of Eq.(8) is defined by the following Eq.

$$P(z^{-1}) := \Delta A_i(z^{-1})S_i(z^{-1}) + z^{-(k_m+1)}B_i(z^{-1})R_i(z^{-1}) \tag{9}$$

It can be seen that $P(z^{-1})$ is the characteristic polynomial of the closed-loop system. The following equation is used to design this polynomial.

$$P(z^{-1}) = 1 + p_1 z^{-1} + p_2 z^{-2} \quad (10)$$

$$\left. \begin{aligned} P_1 &= -2e^{\frac{\rho}{2\mu}} \cos\left(\frac{\sqrt{4\mu-1}}{2\mu}\right) \\ P_2 &= e^{-\frac{\rho}{\mu}} \\ \rho &:= \frac{T_s}{\sigma} \\ \mu &:= 0.25(1-\delta) + 0.51\delta \end{aligned} \right\} \quad (11)$$

σ indicates a parameter corresponding to the rise time, and μ is a parameter related to the damping characteristics of the response, which is adjusted by δ . Here, $R(z^{-1})$ and $S(z^{-1})$ are calculated based on Eq.(9). In order to obtain $R(z^{-1})$ and $S(z^{-1})$ uniquely, it is necessary to set their orders to $n_1 = n_y$ and $n_2 = n_u + k_m$, respectively. In this way, the pole placement control system can be designed for each linear model.

[STEP3] Replacement with PID controller

We have described a control method based on the pole placement method. This method can be replaced by a design method based on PID control if it is considered in the same way as in Eq.(6). First, consider the PID control law of the following Eq.

$$\Delta u(t) = K_I e(t) - K_P \Delta y(t) - K_D \Delta^2 y(t) \quad (12)$$

where, K_P , K_I , and K_D represent the PID gain, respectively. Furthermore, $e(t)$ is the control deviation, which is given by the following Eq.

$$e(t) := r(t) - y(t) \quad (13)$$

Now, Eq.(6) is rewritten as follows

$$\frac{R_i(z^{-1})}{v} y(t) + \Delta u(t) - \frac{R_i(1)}{v} r(t) = 0 \quad (14)$$

In this case, from equations (12) and (14), the PID parameter is given by

$$\left. \begin{aligned} K_P &= \frac{-r_{i,1} - 2r_{i,2}}{v} \\ K_I &= \frac{r_{i,0} + r_{i,1} + r_{i,2}}{v} \\ K_D &= \frac{r_{i,2}}{v} \end{aligned} \right\} \quad (15)$$

The above allows us to adjust the PID parameters based on the approximate pole configuration.

$$v := 1 + s_{i,1} + s_{i,2} \quad (16)$$

[STEP4] Calculation of weights

Next, for each local linear data calculated in [STEP2], the estimation error $\varepsilon_i(t)$ is calculated for each model, and

the weight ω_i is calculated based on this. $\varepsilon_i(t)$ is the error between the system output value $y(t)$ and the estimated output value $\hat{y}(t)$ of each linear model. Here, $\hat{y}(t)$ is calculated based on equation (3) by the following formula

$$\hat{y}_i(t) = -A_i(z^{-1})y(t) + z^{-(k_m+1)}B_i(z^{-1})u(t) \quad (17)$$

where, $A_i(z^{-1})$ and $B_i(z^{-1})$ are the system parameters of each linear model estimated in [STEP1].

$$\varepsilon(t) = |y(t) - \hat{y}_i(t)| \quad (18)$$

$$\omega_i(t) = \frac{\frac{1}{\varepsilon_i(t)}}{\sum_{i=1}^N \frac{1}{\varepsilon_i(t)}} \quad (19)$$

In addition, $\omega_i(t)$ is the weight corresponding to the selected i -th information vector. The smaller the difference between the actual outputs value of the system and each linear model, the larger the value of this weight. Note that the calculation of $\omega_i(t)$ based on equation (18) satisfies the following Eq.

$$\sum_{i=1}^N \omega_i(t) = 1 \quad (20)$$

[STEP5] Generation of weighted PID parameters

Using the weights obtained in [STEP4] and the PID parameters in Eq.(15), calculate the weighted PID parameters using the following Eq.

$$\mathbf{K}(N) = \sum_{i=1}^N \omega_i(t) \mathbf{K}(i) \quad (21)$$

$$\mathbf{K}(i) := [K_P(i), K_I(i), K_D(i)] \quad (22)$$

3. PID tuning method in response to deviation

In contrast to the local linear model-based competitive tuning PID control described in Section 2.2, this section describes a method that performs PID tuning only when a deviation of a certain magnitude occurs. First, we define the threshold as τ , and the condition on τ as follows.

$$\tau > |e(t)| \quad (23)$$

The PID control described in Section 2.2 is performed only when this condition is satisfied; otherwise, the control is performed without changing the PID gain. Here, the parameter τ in equation (23) represents a design parameter given by a certain positive constant. The setting of this parameter requires some trial and error.

4. Simulation

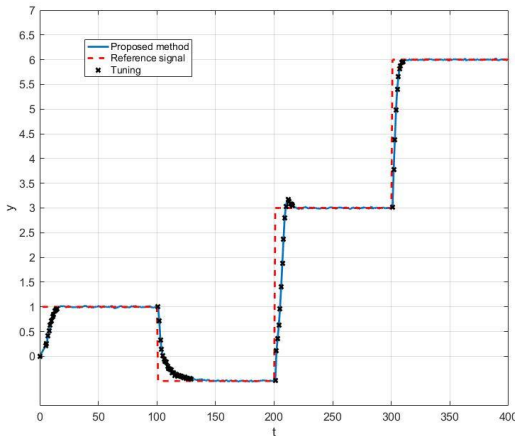


Fig. 1 Control result using the newly proposed PID control scheme

In order to verify the effectiveness of this method, a numerical example for a nonlinear system is presented. The Bilinear model is used as the control target. The Bilinear model, which is expressed by the following equation, is considered as the control target.

$$y(t) = 0.4y(t - 1) - 0.99y(t - 2) + 0.3u(t - 1) - 0.1u(t - 2) + 0.1y(t - 1)u(t - 1) + 0.05y(t - 2)u(t - 2) + \zeta(t) \tag{24}$$

However, $\zeta(t)$ is a Gaussian white noise with mean 0 and variance 0.012. The target value is given as follows.

$$r(t) = \begin{cases} 1.0(0 \leq t < 100) \\ -1.0(100 \leq t < 200) \\ 3(200 \leq t < 300) \\ 6(300 \leq t \leq 400) \end{cases} \tag{25}$$

Next, based on the static characteristics, a linear model corresponding to the control input range is constructed as follows. However, the number of divisions is set to $N=3$. The various design parameters included in this method are $n_y = 2$, $n_u = 1$, and $k_m = 0$.

$$\begin{cases} -4.0 \leq u_1 < 2.0 \\ 2.0 \leq u_2 < 3.4 \\ 3.4 \leq u_3 < 4.0 \end{cases} \tag{26}$$

Furthermore, the threshold τ for determining PID tuning is set to 0.1.

Fig. 2 shows the control results of the proposed method. The points shown in Fig. 2 indicate where the PID gain is being tuned. The results show that the number of times

the PID gain is changed in the proposed method is only 56 step compared to 400 step in the conventional method because the conventional method tunes the PID gain sequentially, which is a significant reduction of about 1/7 times compared to the conventional method.

5. Conclusions

In this paper, a self-tuning control system using a locally linear model that performs PID tuning according to deviations for a nonlinear system is discussed. The effectiveness of the proposed method was verified by simulating a nonlinear bilinear model. In the future, we plan to evaluate the control performance of the deviation threshold setting using item response theory.

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Authors Introduction

Dr. Shinichi Imai



He graduated doctor course at department of engineering in Hiroshima University. He works at department of education in Tokyo Gakugei University. His research area is about control system design, educational engineering.
