Design of Self-Adaptive PID Controller Based on Least square method

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Abstract*—Least square method is widely applied in the field of self-adaptation control for it has well statistical property,such as consistency and unbiasedness.So we can improve the control effect of Second-order System by using least square method in self-adaptive PID control. In this paper a self-adaptive PID controller of Second-order System is discussed.The model of this system is established and simulated in Matlab.The simulation results show that relative to traditional PID control,this method is superior to the former for its quick response, over regulation and robust.Moreover,the controller can adjust rapidly according to the changes of system parameter.

Keywords-component; self-adaptive control; PID; least square method; MATLAB; simulation

I. INTRODUCTION

With the development of industry,we now have so many control methods.But PID control remains a classical control approach in engineering projects. The core element of this method is the parameter tuning for which are P（Proportional）、I（Integral）、D（Derivative）.In most cases,the conventional PID controller can't tuning the parameter smoothly with the uncertain mathematical model of controlled objects.Therefore,people begin to improve the conventional PID controller and design a new controller which can estimates some uncertainty within the system then change a control design automatically.That is called self-adaptive controller.

The first step in controller design is resolving the problem of parameters identification.In system identification there are so many approaches can be used in identifying parameters.Such as least square method, maximum likelihood method ,time series modeling technique and so on.The least square method is proposed by Gauss in his research on orbit measuring of planet and comet. In essence this mathod add the product of difference value and precision then make the accumulated sum to the minimum.Of which the defference value between actual observed value and calculated value. Even though least square method has some limitations,its simple and efficient algorithm make it still a classical method in system identification and is widely used in engineering.

II. FUNDAMENTAL PRINCIPLE OF PID CONTROL

A conventional PID controller system can be depicted in Figure 1.

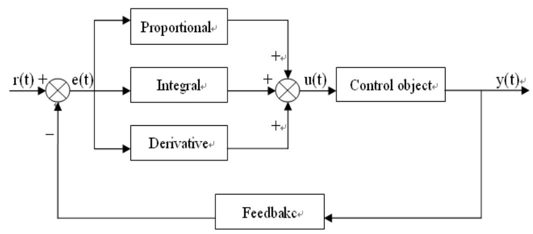

Figure 1. schematic diagram of conventional PID controller

From the diagram,we see that e(t) as the input of PID controller,At the same time, u(t) as the output of controller and the input of object.Then, the control laws of conventional PID will be given by the equation:

$$u(t) = K_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d \frac{de(t)}{dt}] \quad (1)$$

While K_p is proportionality factor, T_i is integral time and T_d is derivative time.

Simply,the proportional element can response proportionate to the error signal.Once the error is produced the controller will reduce the error immediately.The integrate element is used to eliminate steady-state error and integral action depends on T_i .The smaller T_i is the more effective integral element is.The last one is differentiation element.It can predicts the variation trend of error signal and provide a effective corrected signal to system before the error become too big.So it can improve the speed of system and reduce the regulating time[12.p.1].

By using incremental PID formula we can have the output data of the (k-1)th sampling instant:

$$u_{k-1} = K_p[e_{k-1} + \frac{T}{T_i}\sum_{j=0}^{k-1} e_j + \frac{T}{T_i}e_k + T_d \frac{e_{k-1} - e_{k-2}}{T}] \quad (2)$$

Then:

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$$\Delta u = u_k - u_{k-1}$$

$$= K_p(1+\frac{T}{T_i}+\frac{T}{T_d})e_k + K_p(1+\frac{2T_d}{T})e_{k-1} + K_p\frac{T_d}{T}e_{k-2} \quad (3)$$

While:

b1= $K_p(1+\frac{T}{T_i}+\frac{T}{T_d})$, b2= $K_p(1+\frac{2T_d}{T})$, b3= $K_p\frac{T_d}{T}$

Clearly,the key component of controlling a time-variation system is how to identify b1,b2 and b3.

III. LEAST SQUARE METHOD

From (3),we can selcet the following model to tune parameters.The model can be given by the equation as:

$$y(t)=b_1e(k)+b_2e(k-1)+ b_3e(k-2)+v(t) \quad (4)$$

While v(t) is zero-mean-value random noise sequence.

Aiming at this model,let's start the identification by the following steps:

First:

$$\theta^T = [b1, b2, b3]$$

$$\varphi(t) = (\ u(t-1)\ u(t-2)\cdots u(t-n_b))^T$$

When t=1, 2, ···, n, we can have n th equations.Then the equation (4) can be written as:

$$y(t) = H_t\theta + v(t) \quad (5)$$

While: $y(t) = [y(1), y(2),\cdots, y(t)]^T$

$$H_t = [\varphi^T(1), \varphi^T(2),\cdots,\varphi^T(t)]^T$$

$$v_t = [v(1), v(2),\cdots, v(t)]^T$$

Considered the least-squares criterion is:

$$J(\theta) = \sum_{i=1}^{t}[y(i) - \varphi^T(i)\theta]^2 = [y_t - H_t\theta]^T[y_t - H_t\theta]$$

That means,we should use the I/0 data{u(t),y(t)}of the system to make this crierion function to minimum.When we get the minimum value and so we get the estimated value of θ.

Assume $\theta = \hat{\theta}$ and $J(\theta)\big|_{\theta=\hat{\theta}} = \min$. Obtained the first derivative with respect θ to of criterion function , and make the derivative differential coefficient zero .

Then we have the estimate value: [1.p68-70]

$$\hat{\theta} = (H_t^T H_t)^{-1} H_t y_t \quad (6)$$

In order to simplify programming and in view of (6) we can improve the estimate function as:

$$\hat{\theta} = \left(\sum_{t=1}^{N-m}\varphi(t+m)\varphi^T(t+m)\right)^{-1}\sum_{t=1}^{N-m}\varphi(t+m)y(t+m) \quad (7)$$

IV. PID CONTROLLER DESIGN AND SIMULATION RESULT

A. PID CONTROLLER DESIGN

According to the theory above-mentioned,we can use S-function in MATLAB to design a controller.

The steps are:

- By sampling input and output data of system,we can get {y(t),u(t)}.
- Equation (4) shows the parameters which need identifying are b1, b2, b3.
- Comfirm the matrixes θ^T ,$\varphi(t)$.
- Calculate the estimate value $\hat{\theta}$ by using (7).
- Calculate a suitable Δu to be input of object after identifying b1,b2 and b3.The calculate function is given by $\Delta u = b1e_k + b2e_{k-1} + b3e_{k-2}$.

We first progrmming in M-function follow the steps above,and then use M-file S-function to design the controller.

The schematic diagram of the system is shown by Figure 2.

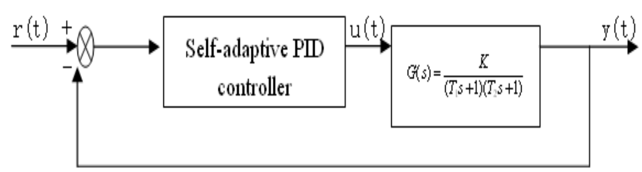

Figure 2. schematic diagram of the system

B. SIMULATION RESULT

We buile a time-varying system in MATLAB,the control object is second-order system which is commonly in engineering.The transfer function is $G(s) = \frac{K}{(T_1s+1)(T_2s+1)}$.

Between 0 ~ 2S the transfer function of object is $\frac{0.5}{2s^2+1.5s}$ and after 2S,it turns to be $\frac{6}{s^2+2.5s+1}$,with unit inverse feedback.In this simulation,we used the step signal as input and step time is 1.

The schematic diagram of controlling by conventional PID controller in simulation is shown as in the Figure 3.If we choose K_p =7, T_i =2, T_d =3the curve is shown in Figure 4.

Then we used the self-adaptive PID controller to replace the conventional PID controller and have the result shown in Figure 5.The simulation model is similar as Figure 3.

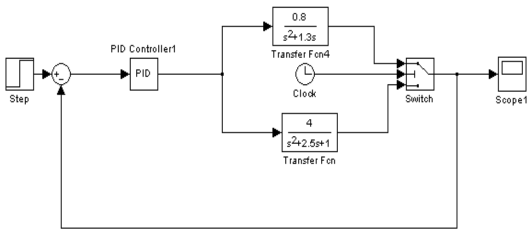

Figure 3. simulation model with conventional PID controller

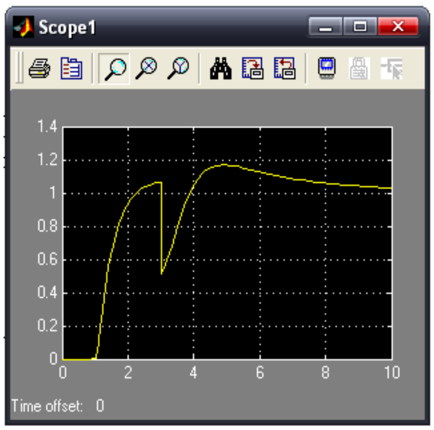

Figure 4. curve of conventional PID control

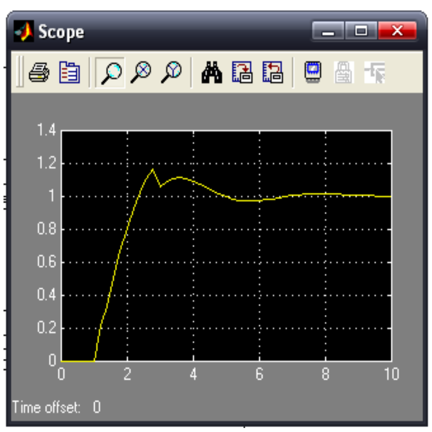

Figure 5. curve of self-adaptive PID control

V. CONCLUSION

In this paper,we use least square method in idetifying parameters of PID controller with input and output data of a time-varying second-order system.After the tuning,we use the parametres to have a suitable u(t) in order to control the object.The diagram of curves will be compared with the curves of conventional PID controller.

Making comparisons of two curves above,we can clearly see that when the object is time-varying or has uncertain mathematical model the conventional PID controller can't adject the changing model and make a bad control.But the self-adaptive PID controller can improve the control effect obviously.

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