슬라이딩 모드 제어기의 채터링 감소 기법

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Technique of Reducing Chattering for Sliding Mode Controller

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Abstract - The sliding mode controller(SMC) is very famous controller for nonlinear control. However the SMC has a defect which is chattering problem. In this paper, we introduce the novel method which reduce the chattering problem. And we compare the performance with conventional methods, such as using low pass filter(LPF), boundary layer approach.

1. Introduction

The SMC is widely used for nonlinear control, because it is an effective to reduce parameter uncertainty and disturbance[1]. However the SMC has a imperfection, it is chattering problem. The chattering involve extremely high control activity and increase electric power consumption. In addition, the chattering produce undesirable highly nonlinearity of the system dynamic[1]. The easiest method is using low pass filter to reduce the chattering. And the boundary layer approach is a common solution. However this method has some problems. First the boundary layer thickness has the trade-off relation between control performance of SMC and chattering migration. Second, within the boundary layer, the characteristic of robustness and the accuracy of the system are no longer assured[2].

Therefore, in this paper, we introduce a novel and simple chattering free SMC which is drived by Lyapunov approach.

2. Technique of reduce chattering

2.1 Conventional SMC

Consider the second order system

$$\begin{aligned} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= f(x) + b(x)u \end{aligned} \tag{1}$$

where f and b are unknown nonlinear functions and $b(x) > b_0 > 0$ for all x. We want to design a sliding mode controller which has sliding surface

$$s = \left(\frac{d}{dt} + \lambda\right)\tilde{x} \tag{2}$$

with a strictly positive constant λ .

Here $\tilde{x} = x - x_d$ is the error in the state where x_d is the desired state. the sliding condition

$$\frac{1}{2}\frac{d}{dt}s^2 \le -\eta|s|, \qquad \eta > 0\ . \tag{3}$$

makes that all trajectories outside the sliding surface point toward the surface, and trajectories on the surface remain there. And the control alw u is verified by sliding condition (3). However the control law has discontinuous term $sgn(s)$ which leads to chattering.

2.2 Boundary layer approach

In the boundary layer approach for SMC, $sgn(s)$ is replaced by $sat(s/\Phi)$, where Φ is the boundary layer thickness[1]. The function $sat(y)$ is defined as

$$sat(y) = \begin{cases} y & \text{, if } |y| < 1 \\ sgn(y) & , otherwise \end{cases}$$

Accordingly, control law u become:

$$u = \hat{u} - \bar{k}(x) sat(s/\Phi)\ .$$

Here the control law doesn't include discontinuous function. Therefore the chattering is reduced. For more detailed description, yon can refer to [1].

2.3 Chattering free SMC

To remove chattering, we use the Lyapunov approach to SMC. Let us choose the following Lyapunov function

$$V = \frac{1}{2}s^2\ . \tag{4}$$

To make the time derivative of (4) the negative definite, we have to find a adequate control law. The control law must be satisfied the following inequality:

$$\frac{1}{2}\frac{d}{dt}s^2 \le -\eta s^2, \qquad \eta > 0\ . \tag{5}$$

We call (5) the sliding condition.

Theorem 1: For a single input second order nonlinear lumped parameter system given by

$$\ddot{x} = fx + u(t)\ ,$$

$$|\hat{f}(x) - f(x)| \le F(x)\ ,$$

where $\hat{f}$ is the estimated function, $F(x)$ is known function. Then the control law is as follows[3]:

$$u = \hat{u} - ks = -\hat{f}(x) + \ddot{x}_d - \lambda\dot{\tilde{x}} - ks, \quad k = \eta + \frac{F(x)}{s}\ .$$

3. Simulations

To confirm the performance of the proposed chattering free SMC, we apply the proposed algorithm to simple nonlinear model[1]. The simple nonlinear system equation is as follows:

$$\ddot{x} + a(t)\dot{x}^2 cos3x = u$$

where $a(t)$ is unknown but verifies

$$1 \le a(t) \le 2\ .$$

Let us design the SMC as follows:

$$s = \dot{\tilde{x}} + \lambda\tilde{x}\ ,$$

$$\hat{f} = -1.5\dot{x}^2 cos(3x)\ ,$$

$$F = 0.5\dot{x}^2|cos(3x)|\ ,$$

$$x_d = sin(\pi t/2)\ .$$

In the case of the conventional SMC, the control input is as follows:

$$u = -\hat{f} + \ddot{x}_d - \lambda\dot{\tilde{x}} - ksgn(s), \quad k = F + \eta.$$

In case of the boundary layer SMC, the control input is as follows:

$$u = -\hat{f} + \ddot{x}_d - \lambda\dot{\tilde{x}} - ksat(s/\Phi), \ k = F + \eta.$$

In case of the using proposed SMC, the contol input is as follows:

$$u = -\hat{f} + \ddot{x}_d - \lambda\dot{\tilde{x}} - ks, \ \ k = \frac{F}{s} + \eta.$$

Here $\eta = 0.1$, $\lambda = 20$, $\Phi = 0.1$.

In Figure 1, the s-trajectories of proposed chattering free SMC and boundary layer SMC have smooth curves but the s-trajectory of conventional SMC doesn't. In Figure 2, we observe that the rough chattering of the s-trajectory of conventional SMC leads to chattering of control input. In Figure 1, the s-trajectory of proposed chattering free SMC is close to zero, whereas the s-trajectory of boundary layer isn't close to zero . Since the s has to converge to zero for good

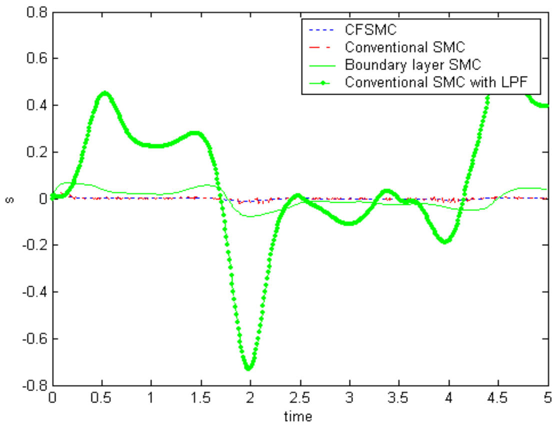

Figure 1. The s-trajectory of each SMC(dotted line: proposed chattering free SMC, dash-dot line: conventional SMC, solid line: Boundary layer SMC, dash-star: Conventional SMC with LPF).

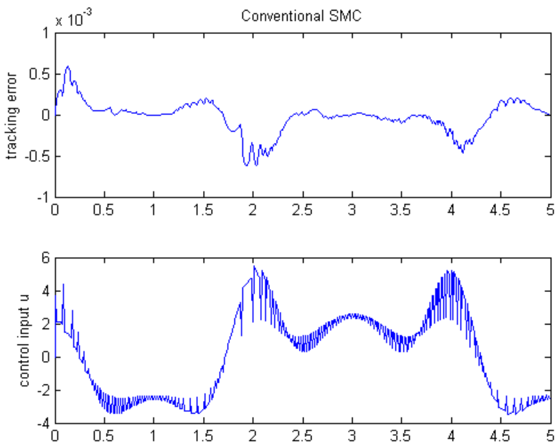

Figure 2. Control input and tracking error with the conventional SMC.

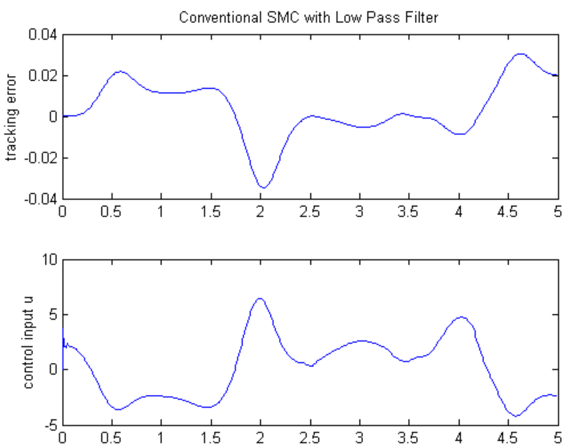

Figure 3. Control input and tracking error of the conventional SMC with low pass filter.

control performance, the proposed chattering free SMC has better performance than the boundary layer SMC. We can observe these in Figure 4, 5. Figure 3 shows control input and tracking error of conventional SMC with low pass filter. The low pass filter exclude

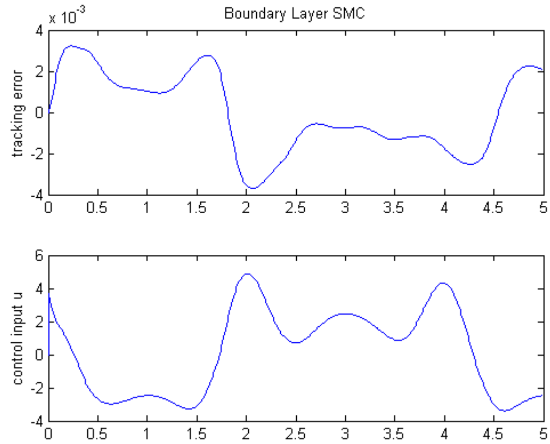

Figure 4. Control input and tracking error with the boundary layer SMC.

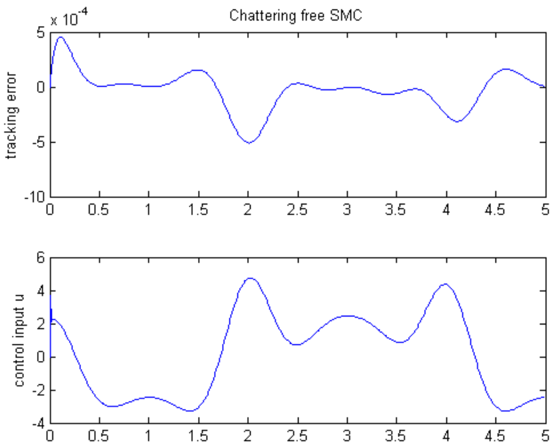

Figure 5. Control input and tracking error with the proposed chattering free SMC.

easily chattering signal, wheres the performance of control get down.

4. Conclusion

In this paper, we introduce the technique of reducing chattering for SMC. Since the chattering in the conventional SMC had been induced by sign function, we eliminated the sign function using Lyapunov approach. To confirm the proposed chattering free SMC, we presented the three simulation results for simple nonlinear model. And we compared the proposed chattering free SMC to the conventional SMC with lowpass filter and the boundary layer SMC which are most common method to reduce chattering.

Consequently, the proposed chattering free SMC removed effectively and has the better performance than another method.

[Acknowledgement]

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