Input Constraints Sliding Mode Control Based on RBF Network Compensation

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Abstract. RBF network is an efficient feed-forward neural network with the best performance and the global optimal approximation properties. Synovial variable structure control has many advantages, such as corresponding fast algorithm, the system parameters and external disturbance invariant, and its algorithm is simple and easy to implement. Thus, it has been becoming a hot spot in recent years to solve the problem of complex nonlinear systems research. This article mainly discusses how to combine the synovial variable structure with the RBF network to produce more superior performance and neural network variable structure control. The algorithm focuses on how to improve the convergence of the network.

Introduction

Slide film control is a method which is used for implementing linear and nonlinear robust control. It is essential to a kind of special nonlinear control, and its nonlinear performance shows the discontinuity of control. Since synovial sliding mode is a variable structure system of systematic parameters, and its external interference is invariable, which means it has nothing to do with system perturbation and distraction, it is thought to be a very obvious control method that draws many researchers' attention and develops rapidly [1].

In practical application, synovial control also has some shortcomings, mainly in the chattering phenomenon. It is susceptible to the effects of measurement noise control and needs large signals to overcome the uncertainty of parameters.

RBF (Redial Basis Function) network is a neural network model which is proposed by J.Moody and C.Darken in the 2080s, which consists of an input layer, one hidden layer and a linear output layer. The biggest advantage is that RBF network belongs to the best approximation properties, and it has no local minima. It also has very strong robustness, nonlinear fitting ability and strong self-learning ability [2]. So it has been widely used in real life.

Sliding mode structure control has some deficiencies, which promotes its RBF network control combination. It enables the system to keep on in the parameter perturbation and robustness. At the same time, it may be as far as to eliminate the occurrence of buffeting. Therefore, through the RBF network and the sliding mode variable structure control of the combination, it can accelerate the response speed of the system, also reduce the system chattering, and strengthen the robustness of the system objective, making its application of synovial control to reduce the obstacles in practice.

Design of RBF synovial controller

System description. Controlled objects can be described in a complex environment.

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = f(x,t) + bu + dt \end{cases} \tag{1}$$

Among them, $b > 0$, dt is the interference $|dt| \le D$, u ,is the limited control.

The maximum value for the control input is $u_{\max}$, $\delta = u - v$, $u = \mathrm{sat}(v)$, Control input constraint function $\mathrm{sat}(v)$ is expressed as :

$$\mathrm{sat}(v)=\begin{cases} u_{\max} & v>u_{\max} \\ v & |v|\le u_{\max} \\ -u_{\max} & v<-u_{\max} \end{cases} \tag{2}$$

Control input constraint function diagram showed in Fig 1.

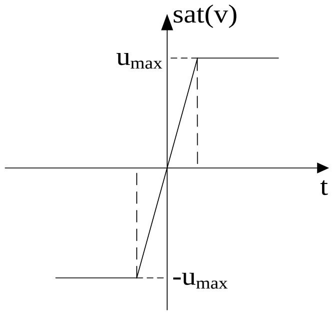

Fig 1. Control input constraint function diagram

Through the design of the RBF network, it uses the method of δ RBF network approximation, the realization of a control input constrained control method based on sliding mode. Closed loop control system schematic diagram shown in Fig 2.

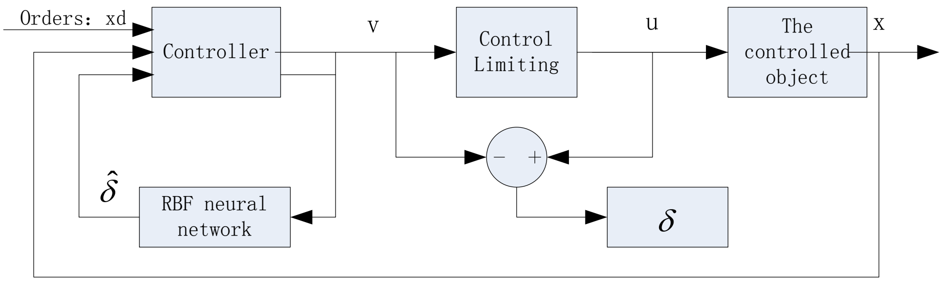

Fig 2. Closed loop control system schematic diagram

Design of RBF synovial controller. The input and output algorithm for RBF network is :

$$h_j=\exp\left(\frac{\left\|\boldsymbol{x}-\boldsymbol{c}_j\right\|^2}{2b_j^2}\right)$$
$$\delta=\boldsymbol{W}^{*\mathrm{T}}\boldsymbol{h}(\boldsymbol{x})+\varepsilon \tag{3}$$

Where $\boldsymbol{x}$ is the input of the network, i stands for the network input layer j number of input. $\boldsymbol{h}=\left[h_j\right]^{\mathrm{T}}$ is the output of Gauss basis function. The researcher can choose $\boldsymbol{W}^*$ as the ideal weight of the networks. ε is an ideal neural network approximation error of δ, $\varepsilon\le\varepsilon_{\max}$, $\hat{\delta}$ is the output of the networks, $\hat{\boldsymbol{W}}$ estimation of weights for neural network.

Including for the Fig 2, the input of network is $\boldsymbol{x}=v$, so the output of the network is:

$$\hat{\delta}=\hat{\boldsymbol{W}}^{\mathrm{T}}\boldsymbol{h} \tag{4}$$

Take $\tilde{\boldsymbol{W}}=\hat{\boldsymbol{W}}-\boldsymbol{W}^*$, so $\delta-\hat{\delta}=\boldsymbol{W}^{*\mathrm{T}}\boldsymbol{h}+\varepsilon-\hat{\boldsymbol{W}}^{\mathrm{T}}\boldsymbol{h}=\left(\boldsymbol{W}^{*\mathrm{T}}-\hat{\boldsymbol{W}}^{\mathrm{T}}\right)\boldsymbol{h}+\varepsilon=-\tilde{\boldsymbol{W}}^{\mathrm{T}}\boldsymbol{h}+\varepsilon$.

Individuals make the control target as $x_1\to x_{\mathrm{d}}$. x_{d} stands for the angle command signal. Definition of angle error is $e=x_1-x_{\mathrm{d}}$, so $\dot{e}=\dot{x}_1-\dot{x}_{\mathrm{d}}$, the sliding node function is :

$$s=ce+\dot{e} \tag{5}$$

Among them, $c > 0$.

So that

$$\dot{s} = c\dot{e} + \ddot{e} = c\dot{e} + \ddot{x}_1 - \ddot{x}_{\mathrm{d}}$$
$$= c\dot{e} + f + bu + dt - \ddot{x}_{\mathrm{d}}$$
$$= c\dot{e} + f + b\left(v + \delta\right) + dt - \ddot{x}_{\mathrm{d}}$$

The control law designs for

$$v = \frac{1}{b}\left(-c\dot{e} - f + \ddot{x}_{\mathrm{d}} - \eta\,\mathrm{sgn}\left(s\right)\right) - \hat{\delta} \tag{6}$$

Include of them, $\eta \geq D + b\varepsilon_{\max}$.

Thus

$$\dot{s} = -\eta\,\mathrm{sgn}\left(s\right) + b\left(\delta - \hat{\delta}\right) + dt = -\eta\,\mathrm{sgn}\left(s\right) - b\tilde{\boldsymbol{W}}^{\mathrm{T}}\boldsymbol{h} + b\varepsilon + dt$$

Definition of the Lyapunov function as

$$L = \frac{1}{2}s^2 + \frac{1}{2}\gamma\tilde{\boldsymbol{W}}^{\mathrm{T}}\tilde{\boldsymbol{W}}$$

Make it, $\gamma > 0$.

Then

$$\dot{V} = s\dot{s} + \gamma\tilde{\boldsymbol{W}}^{\mathrm{T}}\dot{\tilde{\boldsymbol{W}}}$$
$$= -\eta\left|s\right| + s\cdot dt + sb\left(-\tilde{\boldsymbol{W}}^{\mathrm{T}}\boldsymbol{h} + \varepsilon\right) + \gamma\tilde{\boldsymbol{W}}^{\mathrm{T}}\dot{\hat{\boldsymbol{W}}}$$
$$= -\eta\left|s\right| + s\cdot dt + sb\varepsilon + \tilde{\boldsymbol{W}}^{\mathrm{T}}\left(-sb\boldsymbol{h} + \gamma\dot{\hat{\boldsymbol{W}}}\right)$$

Take the adaptation law for

$$\dot{\hat{\boldsymbol{W}}} = \frac{1}{\gamma}sb\boldsymbol{h} \tag{7}$$

Then

$$\dot{V} = -\eta\left|s\right| + \left(dt + b\varepsilon\right)s \leq 0$$

Simulation Examples

Take the controller object as

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -25x_2 + 133u + 10\sin t \end{cases}$$

Then $f\left(x,t\right) = -25x_2$, $b = 133$, $D = 10$.The ideal angle command with $x_{\mathrm{d}} = \sin t$. In order to show the ability of the control system of compensation control with input constraints, investigators shall use the large initial errors, take the initial system vector as $\left[10,0\right]$and also take the RBF network structure as 1-5-1, $\boldsymbol{x} = v$ as the networks inputs. According to the parameters of the network input the actual range to the design of Gauss basis function. Take $\boldsymbol{c}_{\mathrm{i}} = 6\times\left[\text{-1.0} \quad \text{-0.5} \quad 0 \quad 0.5 \quad 1.0\right]$, and $b_j = 5.0$.The initial network weight value is 0, using the control law (6) and the adaptive law (7), taking $c = 5$, $\eta = D + 0.5$, $\gamma = 10$. In sliding mode control, the saturation function is adopted to replace the switching function, taking the boundary layer thickness is 0.02. The simulation results show in Fig 3 and Fig 4. For input constrained values and approximate simulation, showed in Fig 5.

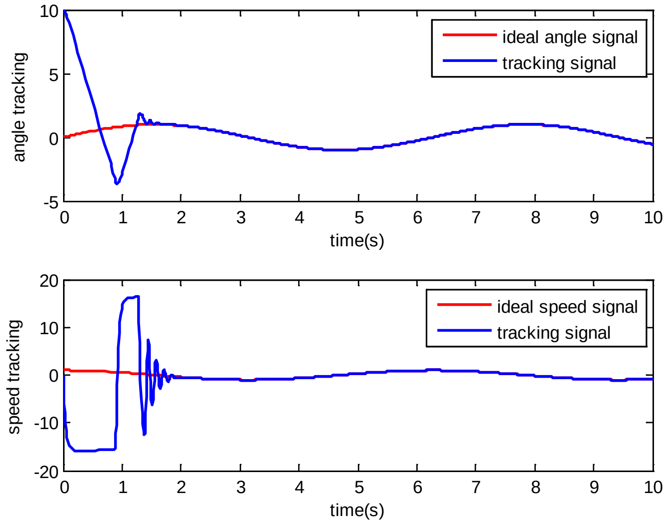

Fig 3.Position and velocity tracking

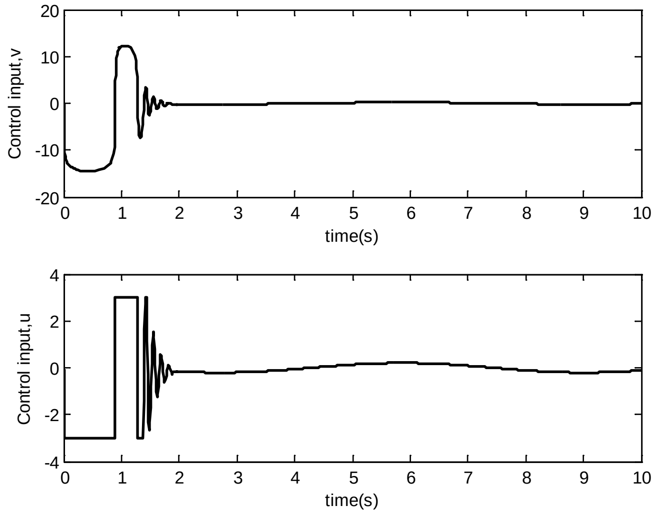

Fig 4.Input v and u before and after constrained control

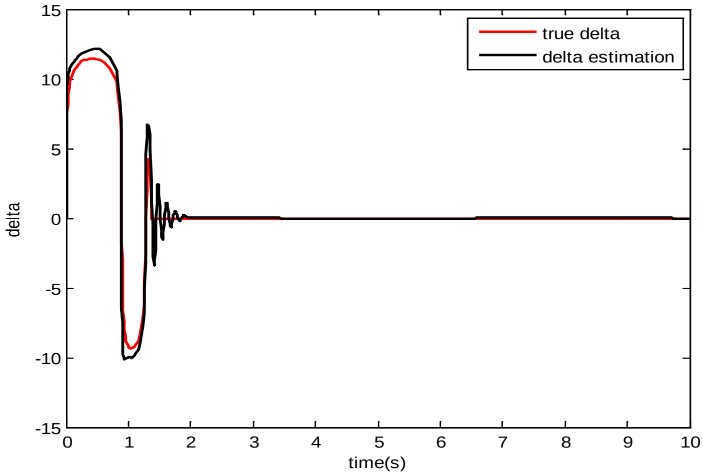

Fig 5.Control input saturation value δ and its approximation

Conclusion

In order to effectively reduce the traditional chattering phenomenon of synovial variable structure control and eliminate the influence of parameter perturbation with external disturbance, the researcher should take the RBF network control into the sliding mode variable structure control by using the approximation capability of RBF network system to approximate unknown nonlinear functions in the model and putting a kind of control input constraint synovial control algorithm based on RBF network compensation. The theoretical and simulation results show that the designed controller can effectively restrain the traditional synovial variable structure, control the stability of the inherent chattering phenomenon and keep a stronger stability.

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