Sliding Mode Control Of Pitch Channel Nonlinear Model Of A Kind Of High Speed Vehicles Without Sign Function

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Abstract. A kind of Sliding mode controller is designed for a kind of pitch channel model of hypersonic aircrafts. The main task is to realize attack angle tracking of hypersonic aircrafts. Compared with traditional sliding mode design method, the main difference is that the sign function is not used and a kind of proportional control item is directly used to reduce the chattering phenomenon. At last, detailed simulations are done to show the rightness of the proposed method.

Introduction

In 1980s, China began to study the concept of near space vehicle, which the main task was to track small space shuttle in the beginning. And in the early of 1990s, CALT proposed the design of "Tianjiao" small space shuttle. In the second half of 2002, "of the aerospace safety issue has been established. The project of "Some key fundamental problems of aerospace safety" has been approved. In April, 2006, the Department of Mathematical Sciences in National Natural Science Fund Committee held a meeting of "near space vehicle development trend and major scientific problem in Foundation seminar". Hypersonic control problem is also a hot and difficult problem in the control field at home and abroad in the last ten years. As academician Huang Lin pointed out, the strong coupling of hypersonic vehicle, classical nonlinear and fast time-varying characteristics of the control of science has brought great challenges. So it is no doubt that the research on the control theory of hypersonic vehicle is of great significance. Based on the above background, a sliding mode control algorithm for a class of hypersonic vehicle is studied in this paper.

Model Description

Considering the elastic shape structure, a kind of pitch channel hypersonic aircraft model built according to Lagrange equation is released by USA air force as followed:

$$\dot{V} = \frac{T\cos\alpha - D}{m} - g\sin\gamma \tag{1}$$

$$\dot{\phi} = -2\varsigma\omega_n\phi - \omega_n^2\phi + \omega_n^2\phi_c \tag{2}$$

$$\dot{\gamma} = \frac{L + T\sin\alpha}{mV} - \frac{g\cos\gamma}{V} \tag{3}$$

$$\dot{\alpha} = q - \dot{\gamma} \tag{4}$$

$$\dot{q} = \frac{M}{I} \tag{5}$$

$$\dot{h} = V\sin\gamma \tag{6}$$

$$\ddot{\eta}_i = -2\varepsilon_m\omega_{mi}\dot{\eta}_i - \omega_{mi}^2\eta_i + N_i \tag{7}$$

Where

$$T = \bar{q}s(C_{T\phi}\phi + C_T + C_T^{\eta}\eta), \quad D = \bar{q}SC_D \tag{8}$$

And V is speed, γ is the speed angle, α is attack angle, Q is the attitude angle speed, h is the height. ϕ is the oil supplying factor, δ_c is the duck wing and δ_e is the lift rudder.

Sliding Mode Controller Design

We first design the control target is $\alpha \rightarrow \alpha^d$, the expected value is $\alpha^d = 1/57.3$. The sliding mode surface is selected as:

$$s = \dot{e} + c_1 e + c_2 q \tag{9}$$

In which $c_1 > 0, c_2 > 0$ from the formula, we can get:

$$\dot{s} = \ddot{e} + c_1 \dot{e} + c_2 \dot{q} \tag{10}$$

In which

$$\dot{q} = M / I_{yy} = \frac{q_b s c_b (c_{m\alpha} + c_{m\delta} + c_{mq})}{-8.03 * 10^{-4} m^2 + 219.74m - 1690000} \tag{11}$$

$c_{m\alpha}$ and c_{mq} are all constant, then the formula (10) derivation can be written as:

$$\dot{s} = u + K\delta \tag{12}$$

in which ,U is intermediate.
Also because:

$$\dot{e} = \dot{\alpha} - \dot{\alpha}^d = \dot{\alpha} = q - \dot{\gamma} \tag{13}$$

While

$$\dot{\gamma} = \frac{L + T \sin \alpha}{mv} - \frac{g \cos \gamma}{v} \tag{14}$$

$$\ddot{e} = \ddot{\alpha} = \dot{q} - \ddot{\gamma} \tag{15}$$

By model parameters, we can get:

$$L = q_b s c_L \tag{16}$$

$$T = q_b s c_T \tag{17}$$

Then brought into the term, we can obtain:

$$\ddot{\gamma} = (\frac{q_b s c_L}{mv})' + (\frac{q_b s c_T}{mv} \sin \alpha)' - (\frac{g \cos \gamma}{v})' \tag{18}$$

So,

$$x_2 = (\frac{q_b s c_T}{mv} \sin \alpha)' \tag{19}$$

$$(\frac{g \cos \gamma}{v})' = \frac{g}{v} \sin \gamma \dot{\gamma} = x_3 \tag{20}$$

Also because

$$e = \alpha - \alpha^d = \dot{\alpha} = q - \dot{\gamma} \tag{21}$$

So,

$$\ddot{e} = \dot{q} - \ddot{\gamma} \tag{22}$$

While

$$\dot{q} = \frac{q_b s c_b \left[c_{m\alpha} + c_{m\delta} + c_{mq} \right]}{I_{yy}} = \frac{q_b s c_b c_{m\alpha} + q_b s c_b c_{m\delta} + q_b s c_b c_{mq}}{I_{yy}} \tag{23}$$

In which,

$$c_{m\delta} = 0.0292\delta - 0.0292\alpha \tag{24}$$

Then

$$\ddot{e} = \dot{q} - \ddot{\gamma} = y + (\frac{0.0292 q_b s c_b \delta}{I_{yy}}) - \ddot{\gamma} \tag{25}$$

Also because:

$$\dot{s} = \ddot{e} + c_1 \dot{e} + c_2 \dot{q} \tag{26}$$

From the previous formula $\dot{s} = aaa + K\delta$, it can be concluded that:

$$k = \left(\frac{0.0292 q_b s c_b (1 + c_2)}{I_{yy}}\right) \tag{27}$$

So

$$aaa = (1 + c_2)y - c_1 q - c_1 \dot{\gamma} - \ddot{\gamma} \tag{28}$$

$$\dot{s} = aaa + k\delta \tag{29}$$

$$k\delta = -aaa - 5s \tag{30}$$

To sum up, we can get:

$$\delta = \frac{-aaa - 5s}{k} \tag{31}$$

Design of angle tracking sliding mode controller is as follows:

$$\delta = \frac{-aaa - 5s}{k} \tag{32}$$

Simulation Results

According to the controller design procedures, simulation results can be obtained as shown below:

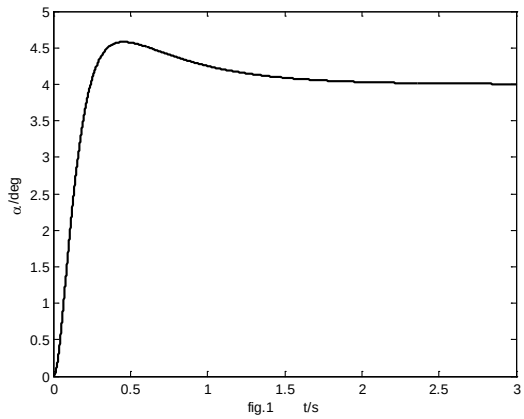

Fig. 1 Angle of attack curve

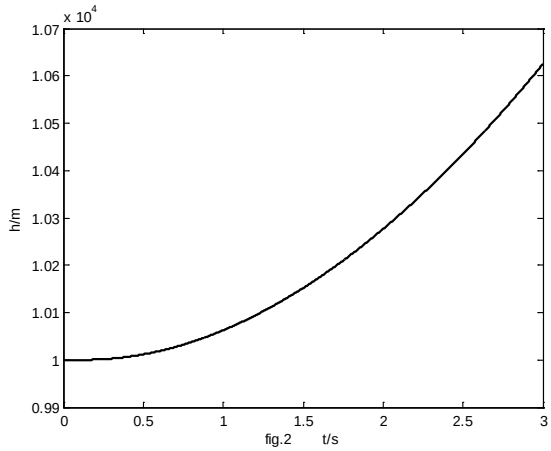

Fig. 2 Height curve

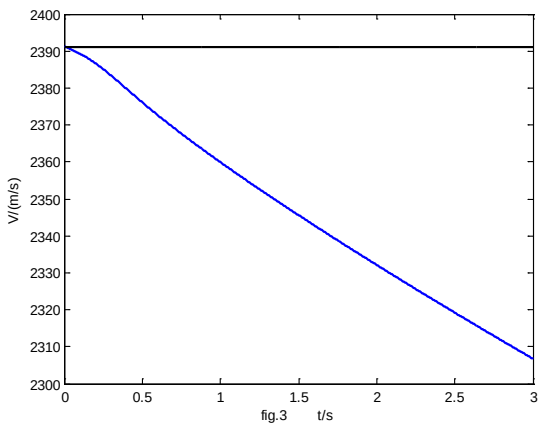

Fig. 3 Velocity curve

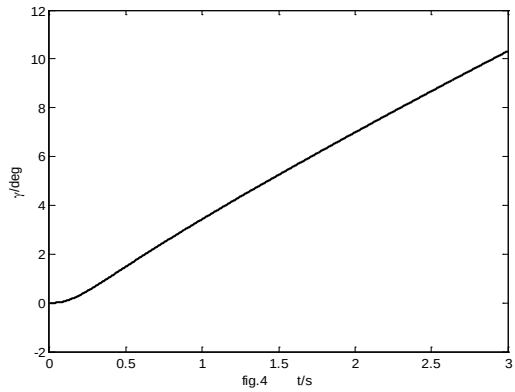

Fig.4 Speed inclination curve

From the above simulation results,we can see that in the procedure, referencing the sliding mode control method and designing the desired sliding mode surface and the equivalent control law can quickly respond to the input transformation. What's more ,It is not sensitive to the parameter transformation and the disturbance, which can overcome the uncertainty of the system, and has strong robustness to the disturbance and the non modeling dynamics. Especially it has good effect in the control of nonlinear system [8].

Conclusions

According to the nonlinear model of hypersonic vehicle pitch channel, this paper gives the angle tracking controller for a class of sliding mode control design method, and the digital simulation verified the correctness and effectiveness of the method. And the difference between it and traditional sliding mode control method is that this paper does not use the symbolic function mainly to avoid the flutter but introduces a simple proportional control. The simulation results show that the scheme is feasible.

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