Adaptive Sliding Mode Control of Airship Pitch Channel Attitude Angle

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Abstract. On the basic of nonlinear model of pitching channel of airship, assuming the condition that the information of the unknown portion of the assumed airship model satisfy the norm-bounded condition and the boundary is known. A adaptation method has been used to solve the unknown information problem in this paper, and this paper has proposed a class of sliding mode control method in order to control attitude angle of pitching channel of airship. Finally, this control method is proved to be effective by numerical simulation.

Introduction

As a aerial platform, airship has unique advantage, such as low cost, long hang time, large load ability, small noise, low power consumption, excellent security, high cost-effectiveness and so on.

But there is a lot of information about the design of airship and stability analysis, and there is little information about the control system of airship for secrecy reason.

In 1998, Brazil AURORA project team of stratospheric airship published initial literature[1]. Literature[1] has given YEZ-2A airship's six degree-of-freedom model that has been confirmed by test flight, and literature[2] has analysed the part of dynamic response.

On the basic of six degree-of-freedom model of airship, this paper extracts the simplified nonlinear model of pitching channel for the research about airship control. Because the airship model has its irresistible inaccuracy or unknown, but the inaccuracy or unknown satisfy he norm-bounded condition and the boundary is unknown, this paper proposes a control that combines self-adaptation and sliding mode control to control airship attitude. Finally, this control method is proved to be effective by numerical simulation.

Model Description

Based on the previous work, the pitch channel model of airship can be described as follows:

$$M\dot{x} = f(x) + g(x)u \tag{1}$$

And $x = [u \quad w \quad q \quad \theta \quad x \quad z]$, M satisfies

$$M^{-1} = \begin{bmatrix} a_{11} & & a_{13} & & & \\ & a_{22} & & & & \\ a_{31} & & a_{33} & & & \\ & & & 1 & & \\ & & & & 1 & \\ & & & & & 1 \end{bmatrix} \tag{2}$$

The definition of a_{ij} see the definition of M in previous work[3-5].

Choose the expect value of all states u, w, q, θ, x, z are $u^d, w^d, q^d, \theta^d, x^d, z^d$,Define the error variable $e = x - x^d$, $\dot{e} = \dot{x}$, then it hold

$$M\dot{e} = f(x) + g(x)u \tag{3}$$

Use the inverse matrix of M

$$\dot{e} = M^{-1} f(x) + M^{-1} g(x) u \tag{4}$$

To make it convenient for reading, some functions can be written as follows[6-8]

$$f(x) = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix}, \quad g(x) = \begin{bmatrix} 0 & 1 \\ k_1 & 0 \\ k_2 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \quad u = [u_1 \quad u_2]^T \tag{5}$$

where

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix} = \begin{bmatrix} -(m+m_{33})wq + Q[C_{X1}\cos^2\alpha + C_{X2}\sin(2\alpha)\sin(\alpha/2)) \\ (m+m_{11})qu + ma_z q^2 + Q[C_{z1}\cos(\alpha/2)\sin(2\alpha) + C_{z2}\sin(2\alpha) + C_{z3}\sin(\alpha)\sin(|\alpha|)] \\ -ma_z wq(-rv) + Q[C_{M1}\cos(\alpha/2)\sin(2\alpha) + C_{M2}\sin(2\alpha) + C_{M3}\sin(\alpha)\sin(|\alpha|)] - a_z \sin\theta W \\ q \\ u\cos\theta + w\sin\theta \\ -u\sin\theta + w\cos\theta \end{bmatrix}$$

Define[9]

$$M^{-1} f(x) = \begin{bmatrix} f_{a1} \\ f_{a2} \\ f_{a3} \\ f_{a4} \\ f_{a5} \\ f_{a6} \end{bmatrix} = \begin{bmatrix} a_{11} f_1 + a_{13} f_3 \\ a_{22} f_2 \\ a_{31} f_1 + a_{33} f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix} \tag{6}$$

And

$$g(x)u = \begin{bmatrix} u_2 \\ k_1 u_1 \\ k_2 u_1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{7}$$

Then the system can be written as follows

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \\ \dot{x} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} f_{a1} \\ f_{a2} \\ f_{a3} \\ f_{a4} \\ f_{a5} \\ f_{a6} \end{bmatrix} + \begin{bmatrix} a_{11}u_2 + a_{13}k_2 u_1 \\ a_{22}k_1 u_1 \\ a_{31}u_2 + a_{33}k_2 u_1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{8}$$

Robust Sliding Mode Control of Attitude

Assume that the airship moves at constant speed and attitude, and assume angle of pitch $\theta^d = 2/57.3$, then define sliding mode surface[10-11]:

$$s_1 = c_1(\theta - \theta^d) + q \tag{9}$$

Differentiate the sliding mode surface

$$\dot{s}_1 = c_1 q + \dot{q} = c_1 q + a_{31} f_1 + a_{33} f_3 + a_{31} u_2 + a_{33} k_2 u_1 \tag{10}$$

Consider decoupling control, u_1 controls vertical movement and u_2 controls forward movement, then design:

$$u_2 = Cons \tag{11}$$

Assume $a_{31} f_1 + a_{33} f_3$ is bounded and the boundary is known, then[12-15]:

$$a_{31} f_1 + a_{33} f_3 < d_1 a_{33} k_2 \tag{12}$$

If the boundary is unknown, choose the value of the boundary $\hat{d}_1$, the design control law as follow:

$$u_1 = u_{1b} = -k_0 s_1 - \hat{k}_1 s_1 - \hat{k}_2 q - \hat{d}_1 sign(s_1) - \hat{k}_4 u_2 \tag{13}$$

then

$$\begin{aligned} s_1 \dot{s}_1 \le & -a_1 s_1 s_1 + (c_1 - a_{33} k_2 \hat{k}_2) q s_1 + (a_{31} f_1 + a_{33} f_3 - a_{33} k_2 \hat{d}_1) s_1 \\ & + (a_{31} - a_{33} k_2 \hat{k}_4) u_2 s_1 + (a_1 - a_{33} k_2 k_0 - a_{33} k_2 \hat{k}_1) s_1 s_1 \end{aligned} \tag{14}$$

It can be got by simplifying

$$\begin{aligned} s_1 \dot{s}_1 \le & -a_1 s_1 s_1 + (c_1 - a_{33} k_2 \hat{k}_2) q s_1 + d_1 |s_1| - a_{33} k_2 \hat{d}_1 |s_1| \\ & + (a_{31} - a_{33} k_2 \hat{k}_4) u_2 s_1 + (a_1 - a_{33} k_2 k_0 - a_{33} k_2 \hat{k}_1) s_1 s_1 \end{aligned} \tag{15}$$

Define:

$$\tilde{d}_1 = d_1 - a_{33} k_2 \hat{d}_1 \tag{16}$$

then

$$\dot{\tilde{d}}_1 = -a_{33} k_2 \dot{\hat{d}}_1 \tag{17}$$

Where

$$\dot{\hat{d}}_1 = \Gamma_d s_1 \tag{18}$$

So

$$\left[\frac{1}{2\Gamma_d a_{33} k_2} (\tilde{d})^2 \right]' = -\tilde{d} s_1 \tag{19}$$

choose a Lyapunov function as[16-19]:

$$V_c = \frac{1}{2} s_1^2 + \sum_{i=1, i\ne 3}^{4} \left[\frac{1}{2\Gamma_i a_{33} k_2} (\tilde{k}_i)^2 \right] + \frac{1}{2\Gamma_i a_{33} k_2} (\tilde{d})^2 \tag{20}$$

So

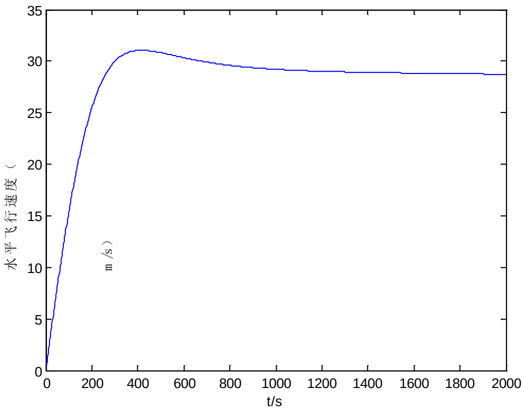
$$\dot{V}_c \le -a_1 s_1^2 \le 0 \tag{21}$$

It is not difficult to prove that system is stable in hypothetical condition.

Numerical Simulation

The system is proved to be stable by theoretical derivation as above, in order to test the stability of the system, this section uses SIMULINK tool case in MATLAB to the simulation.

In this section, choose $u_2 = 10000$, assume that the initial height is 1 meter, assume that attitude angle is 20 degree, and choose $d_1 = 0.01$, simulation results are as follows:



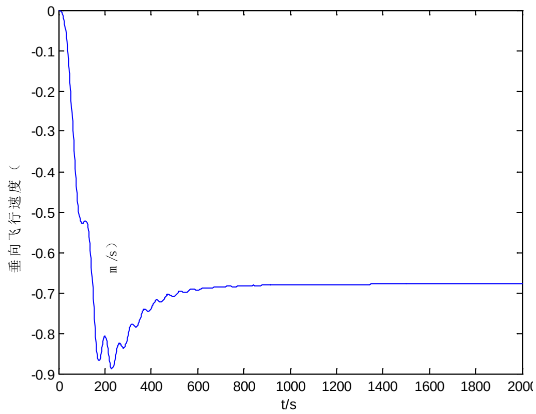
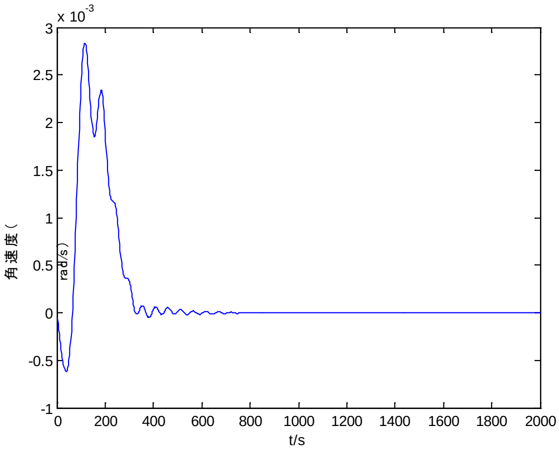


Fig. 1 Forward Velocity Fig. 2 Vertical Velocity



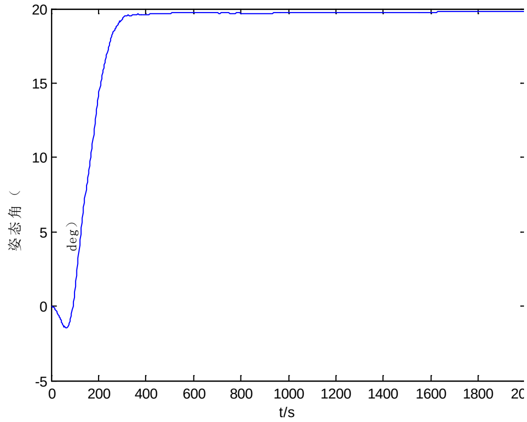
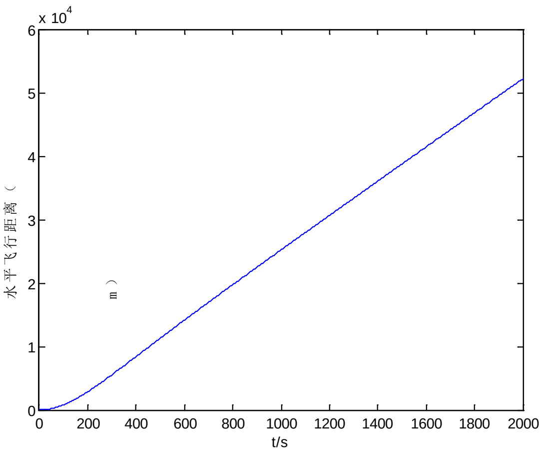


Fig. 3 Angle Velocity Fig. 4 Pitch Angle



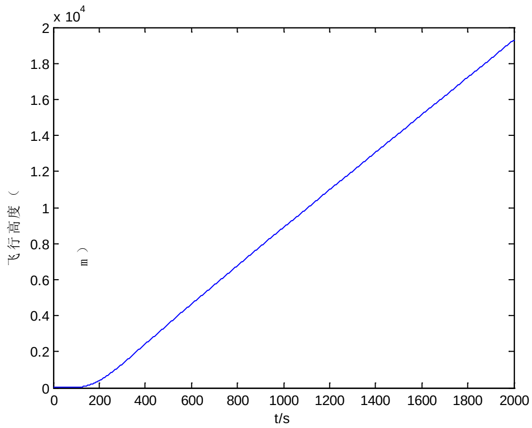


Fig. 5 Flying Distance Fig. 6 Height

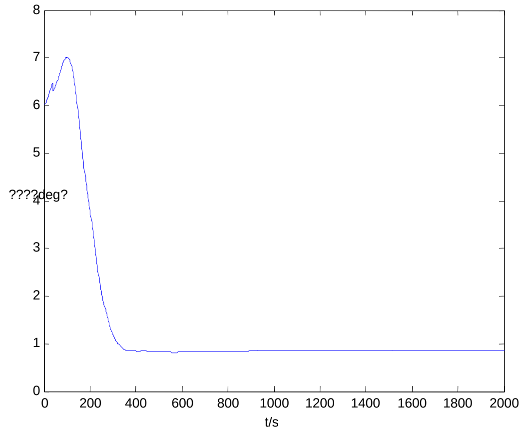


Fig. 7 Actuator Angle

Conclusion

This paper proposes a control that combines self-adaptation and sliding mode control to solve problem that some information in nonlinear model of pitching channel of airship are unknown. On the basic of nonlinear model of pitching channel of airship, this paper proposes a control that combines self-adaptation and sliding mode control in hypothetical condition that the information of the unknown portion of the system satisfy the norm-bounded condition. The simulation results show that the vibration chatter of system and offset of attitude angle is alleviated and the gain of controller don't need to be raise. So the control method preposed in this paper is better than smooth function from the point of alleviating offset.

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