Modeling And Robust Sliding Mode Control Of A Kind Airship Aircraft

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Keywords: airship; pitch channel; adaptive; robustness; modeling

Abstract. The airship modeling is the basic of the airship control problem, a class of simplified nonlinear model of pitching channel is studied in this paper. On the base of all above mentioned, the speed control is separated from the attitude control, and the speed is controlled by a simple constant control scheme. This paper has proposed a control scheme that is similar to robust sliding mode control scheme in the condition that the information of the unknown portion of the assumed airship model satisfy the norm-bounded condition and the boundary is known. Finally this control scheme is proved to be effective by detailed numerical simulation.

Introduction

The wide application value and prospects of airship attracts notice all around word, and more and more literature cover it.

In airship control process, little perturbation method is mainly used in attitude control. The little perturbation can decouple the whole system into two standalone linear system. In order to make the system parameter be not sensitivity to disturbance out of the system. Literature[1] translated system into a SISO system by introducing internal feedback and designed a controller for the system. Literature[2] used traditional PID control method to design a inside and outside controller for little perturbation linear system. Literature[3] decoupled airship nonlinear model with six degree of freedom into the vertical and horizontal movement model and used PI control method to study trajectory-tracking problem of airship.

Based on airship nonlinear model of pitching channel and attitude control task, and the system is assumed that the information of the unknown portion of the system satisfy the norm-bounded condition and the boundary is known, a control scheme that combines robust control method and sliding mode control scheme is used to design a pitching channel attitude-tracking controller in this paper. Finally, this control method is proved to be effective by detailed numerical simulation.

Model Description

Based on the previous work, the pitch channel model of airship can be described as follows[4-10]:

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

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.

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[11]

$$g(x) = \begin{bmatrix} 0 & 1 \\ k_1 & 0 \\ k_2 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \tag{5}$$

Where[12-13]

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

Define

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

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:

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

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[14-17]:

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

Assume $a_{31} f_1 + a_{33} f_3$ is bounded and the boundary is known, then:

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

There are some improvements to the above control law, design:

$$u_1 = u_{1a} = -k_0 s_1 - \hat{k}_1 s_1 - \hat{k}_2 q - d_1 sign(s_1) - \hat{k}_4 u_2 \tag{13}$$

choose a Lyapunov function as[18-20]:

$$V_b = \frac{1}{2} s_1^2 + \sum_{i=1, i\neq 3}^{4} \left[\frac{1}{2\Gamma_i a_{33} k_2} (\tilde{k}_i)^2 \right] \tag{14}$$

It is not difficult to prove that:

$$\dot{V}_b \le 0 \tag{15}$$

So system is stable.

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, and choose $d_1 = 0.01$, then simulation results are as follows:

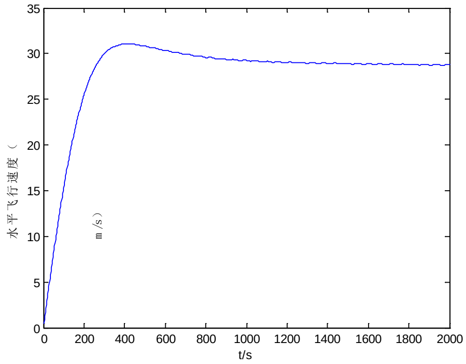

Fig. 1 Forward Velocity

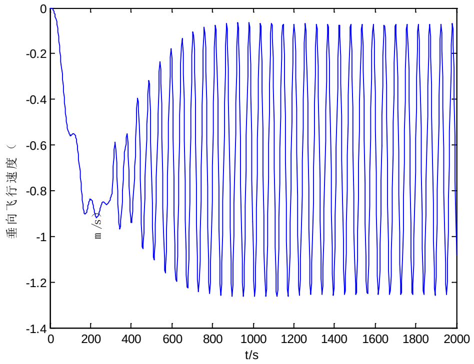

Fig. 2 Vertical Velocity

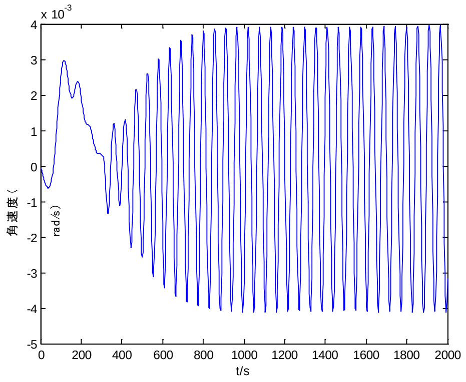

Fig. 3 Angle Velocity

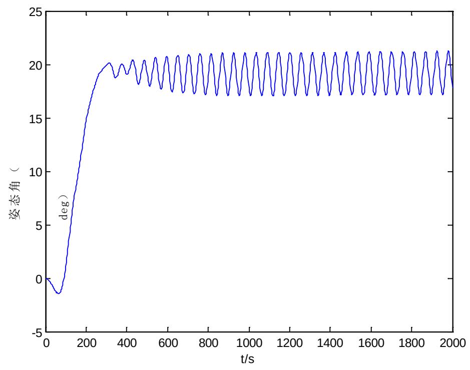

Fig. 4 Pitch Angle

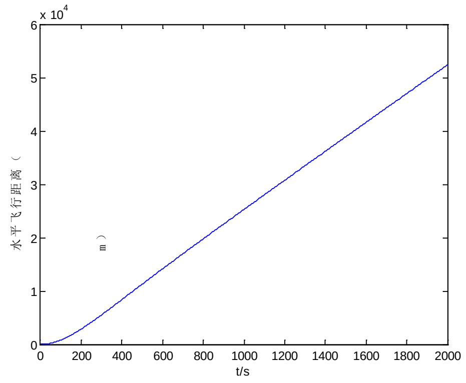

Fig. 5 Flying Distance

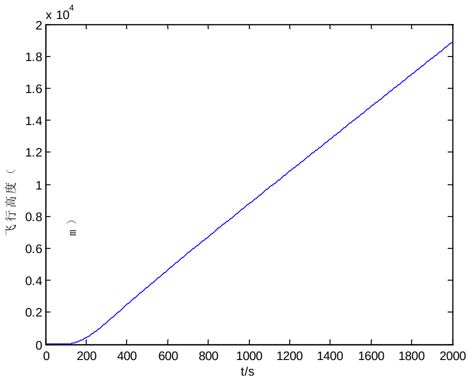

Fig. 6 Height

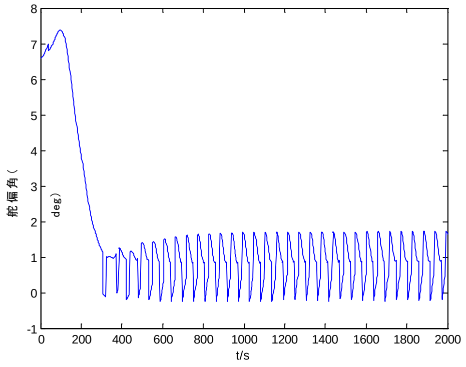

Fig. 7 Actuator Angle

From the simulation results, a conclusion can be got that there are big vibration chatter in system (attitude angle, nonhyperbolic moveout, speed of attitude angle rotation) as sign function is introduced. Though it has little effect on flight path, the airship is unstable. So smooth function can be considered to substitute for sign function.

$$\frac{s}{|s|+\sigma} \approx \operatorname{sgn}(s) \tag{16}$$

Simulation results are as follows:

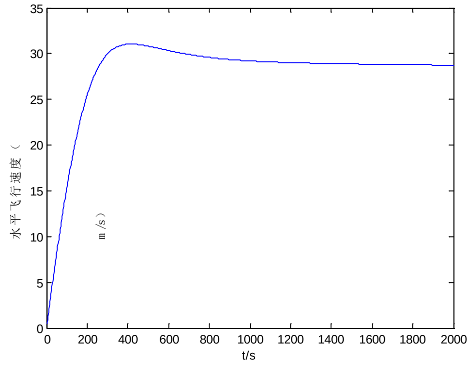

Fig. 8 Forward Velocity

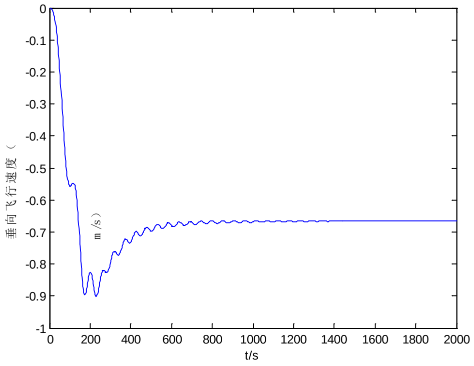

Fig. 9 Vertical Velocity

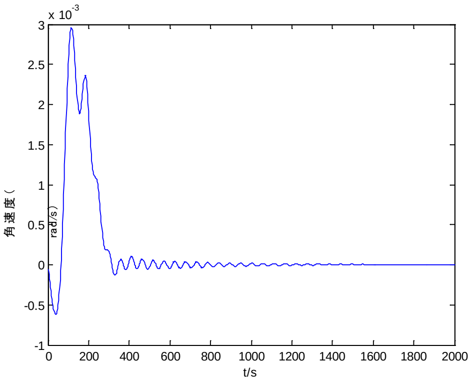

Fig. 10 Angle Velocity

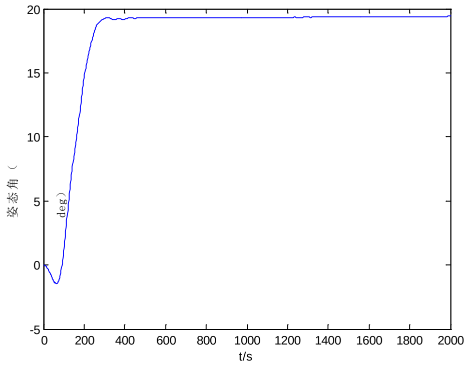

Fig. 11 Pitch Angle

Conclusion

In this paper, a nonlinear model of pitching channel of airship has been established, In the condition that the information of the unknown portion of the assumed airship model satisfy the norm-bounded condition and the boundary is known, this paper has proposed a control scheme that is similar to robust sliding mode control scheme. The simulation results show that smooth function can alleviate vibration chatter, the insufficiency of smooth function is that there is offset in system, but the offset can be eliminated by adjusting coefficient. this control method is proved to be effective by numerical simulation.

References

[1] Kaempf B G, Well K H. Attitude control system for a remotely-controlled airship. AIAA 1995-1622, 1995

[2] Mueller J B, Paluszek M A, Zhao Y. Development of an aerodynamic model and control law design for a high altitude airship. AIAA 2004-6479,2004

[3] Hygounenc, E., I.K.Jung, P.Soueres, et al., The autonomous blimp project of LAAS-CNRS: Achievements in flight control and terrain mapping. 2004.23:473-511

[4] L.B.Tuckerman.Inertia Factors of Ellipsoids for Use in Airship Design. Naca Reports. 2006,14(3):45~50

[5] E.C.de Paiva,S.S.Bueno,Influence of Wind Speed on Airship Dynamics, Journal of Guidance, Control and Dynamics. 2002,25(6):116~124

[6] Sergio B.Varella Gomes and Josue Jr.G.Ramos.Airship dynamic modeling for autonomous operation.Proceedings of the 2003 IEEE. International Conference on Robotics&Automation. 2003:5~14

[7] J.S.Uhlman,N.E.Fine,D.C.Kring.Calculation of the Added Mass and Damping Forces on Supercavitating Bodies.The 4th International Symposium on Cavitation,California,2001:7~13

[8] D.Clarke.Calculation of the Added Mass of Elliptical Cylinders in Shallow Water.Ocean Engineering.2001,28(4):61~72