Integral Sliding mode Control of Height Loop of a Kind of Airship Vehicle

Yuqiang Jin¹, Huali Wu and Junwei Lei²

¹Department of Training, Naval aeronautical and astronautical University

Yanti, 264001

²Department of Control engineering, Naval aeronautical and astronautical University

Yanti, 264001

^ajinyuqiang1024@126.com

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Abstract. A kind of integral sliding mode surface method is firstly used in the height loop of airship system based on the assumption that the pitch angle control loop is stable. The expected pitch angle signal is caused by the sliding mode surface which is produced by height error. Compared with traditional PID height loop control strategy, this integral sliding mode method has a very quick output response and simulation result shows that the proposed method is also very accurate in the task of tracking of desired height.

Introduction

In recent years, due to its potential application value in military, the airship has attracted the attention of researchers from many countries^[1-5]. The height control loop of the airship is based on the complete design of the inner loop, which is also called attitude angle tracking loop. At present, PID control is widely used in the transformation from height command signal to attitude angle, but the main problem of this method is that the parameters need to be set in advance. It is difficult to achieve a set of parameters for all the desired height^[6-10]. At the same time, it is difficult to guarantee the rapidness in height control. Based on the above reasons, this paper puts forward a kind of integral sliding mode control method, which can effectively increase the speed and accuracy of the height control due to the introduction of the integral term.

Model Description

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

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

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

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

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

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

Use the inverse matrix of M

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

To make it convenient for reading, some functions can be written as follows

$$f(x) = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix} u = \begin{bmatrix} u_1 & u_2 \end{bmatrix}^T \quad (5)$$

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

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

And

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

Then the system can be written as follows[8-9]

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \\ \dot{x} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} f_{a1} \\ f_{a2} \\ f_{a3} \\ f_{a4} \\ f_{a5} \\ f_{a6} \end{bmatrix} + \begin{bmatrix} a_{11}u_2 + a_{13}k_2u_1 \\ a_{22}k_1u_1 \\ a_{31}u_2 + a_{33}k_2u_1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (8)$$

Sliding mode controller design for height loop

Below design and research is based on the assumption that the pitch angle control system of airship is effective so the goal of height loop is to design the desired or expected value of pitch angle.

Assume the expected height is z^d , and define the error variable as

$$e_z = z - z^d \quad (9)$$

Then according to the above model, its derivative can be solved as

$$\dot{e}_z = \dot{z} = -u \sin \theta + w \cos \theta \quad (10)$$

And choose a integral sliding mode surface as

$$s_z = c_z e_z + c_{zs} \int e_z dt + \dot{e}_z \quad (11)$$

Solve its derivative as

$$\begin{aligned} \dot{s}_z &= c_z \dot{e}_z + \ddot{e}_z + c_{zs} \dot{e}_z = c_z \dot{z} + \ddot{z} + c_{zs} \dot{e}_z \\ &= -c_z u \sin \theta + c_z w \cos \theta + (-u \sin \theta + w \cos \theta)' + c_{zs} \dot{e}_z \end{aligned} \quad (12)$$

where

$$(-u \sin \theta + w \cos \theta)' = -\dot{u} \sin \theta + \dot{w} \cos \theta - (u \cos \theta + w \sin \theta)q \quad (13)$$

then

$$\dot{s}_z = -c_z u \sin \theta + c_z w \cos \theta - \dot{u} \sin \theta + \dot{w} \cos \theta - (u \cos \theta + w \sin \theta)q + c_{zs} \dot{e}_z \quad (14)$$

Design the expected value of pitch angle as

$$\theta = [k_{z1}s_z + k_{z2}s_z / (|s_z| + \xi)] + d_t \text{sign}(s_z) \quad (15)$$

And define

$$\Delta = c_z w \cos \theta - \dot{u} \sin \theta + \dot{w} \cos \theta - (u \cos \theta + w \sin \theta)q + c_{zs} \dot{e}_z \quad (16)$$

where

$$\dot{s}_z = -c_z u \sin [k_{z1}s_z + k_{z2}s_z / (|s_z| + \xi)] + \Delta \quad (17)$$

For the following inequality, there exist positive constant k_{p1} and k_{p2} such that

$$k_{p1}\theta^2 \leq \theta \sin \theta \leq k_{p2}\theta^2 \quad (18)$$

For a small θ , when Δ compare with θ , it can satisfy $\Delta < d_r\theta$, so

$$\theta \dot{s}_z = -c_z \theta u \sin[\theta] + \Delta \theta \quad (19)$$

Then it holds

$$[k_{z1} + k_{z2}/(|s_z| + \xi)]s_z \dot{s}_z \leq -c_z u k_{p1}\theta^2 + d_r\theta^2 \quad (20)$$

So it is easy to choose proper control gain such that

$$s_z \dot{s}_z \leq 0 \quad (21)$$

And according to Lyapunov stable theorem, the system is stable.

Numerical simulation

To testify the rightness of the above method, a numerical simulation is done as follows: choose control parameter as $c_z = 0.06$, set $k_{z1} = 0.1, k_{z2} = 5, \xi = 10$, then assume $u = 20 \text{ m/s}$, $T_m = 8000 \text{ N}$, initial position $x_e = y_e = z_e = 0$. Other quantity of state is 0, choose $z_d = -500$, simulation results are as following figures:

Fig.2 Forward Velocity

Fig.3 Vertical Velocity

Fig. 4 Angle Velocity

Fig.5 Pitch Angle

Fig. 6 Flying Distance

Fig. 7 Height

Fig. 8 Pitch Actuator Angle

Fig. 9 Expected value of pitch angle

The simulation results show that airship can follow the tracks of expected altitude 500s, and the speed of airship is about 25m/s, and the rise time of response of height loop is about 200s, which is very quick for an airship system, so simulation result shows that the height control system is effective and stable.

Conclusion

A kind of integral sliding mode method is firstly used to generate the command signal of pitch angle which can make the height of airship track the desired value. So this novel method is totally different from traditional height control method such as PID method. And the advantage which is showed by the detailed simulation is that the tracking of desired height can be a very big value and the actuator angle can also avoid saturation problem, also the response is very quick and accurate.

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