A Simple Fuzzy Backstepping Integral Compound Control Method for Saucer-shaped Aircraft

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Abstract. In order to solve the problem of insufficient output stability accuracy of saucer-shaped aircraft with simplified non-minimum phase linear model, a fuzzy backstepping and integral compound method is designed based on the fuzzy backstepping control by measuring the attitude angle and angular velocity of the aircraft. By means of Lyapunov function, the stability of all closed-loop signals of the whole system is proved. Finally, the numerical simulation shows that the proposed method is correct, but the output has a certain oscillation and overshoot, and the overshoot is caused by improper gain matching due to the backstepping control, while the introduction of the integration also increased the oscillation to some extent.

Introduction

Conventional aircraft achieves the flight control by adjusting the rudder deflection, while the saucer-shaped aircraft is a kind of unconventional aircraft without tail or rudder [1-3], and its flight can be achieved by variable mass moment and thrust vector compound control [4-5]. However, this control method has brought a series of technical problems, one of which is how to deal with a highly nonlinear multi-input system. In this paper, the linear equation is obtained by simplifying the longitudinal motion of the aircraft with use of small deviation linearization method. Since the simplified linear system is unstable and non-minimum phase, the traditional control method cannot be used. So there are many scholars put forward a variety of control methods. For example, the literature [5] proposed a hybrid control strategy based on genetic fuzzy logic, and neural sliding mode control is proposed in literature [6-7], and the backstepping control and fuzzy backstepping control are proposed in literature [8-11]. However, these control methods cannot guarantee the accuracy of control when the system is subject to high interference or high rate of change. Therefore, this paper proposes a fuzzy backstepping integral control algorithm, which can improve the robustness and stability of the system.

Model Description

According to literature [5], the ordinate dynamic model for saucer-shaped aircraft can be described as formula 1.

$$\begin{cases} M\dot{v} = -X - Mg\sin\theta + P\cos(\xi+\alpha) \\ Mv\dot{\theta} = Y - Mg\cos\theta + P\sin(\xi+\alpha) \\ J'_z\dot{\omega}^b_{dbz} = X_P P\sin\xi + y_T P\cos\xi + M_z + M_z(x_b) - \mu P\sin\xi\cdot x_b \\ \dot{\vartheta} = \omega^b_{dbz} \end{cases} \tag{1}$$

Theorem1: Assume the linear approximation system of nonlinear system is asymptotically stable, and then any linear feedback that can make the linear approximation system stable can also asymptotically stabilize the original nonlinear system, and at least make the nonlinear system locally stable.

The linear dynamic model of missile is studied in literature [12]. Similarly, we can also study the linear approximation system of nonlinear system as described in formula 1, in order to find the control law which can make the original nonlinear system asymptotically stable. According to the literature [5], the linear approximation system for the system as described in formula 1 can be presented in formula 2.

$$\begin{cases} \dot{\omega}_z = -a_{24}\theta + a_{24}\vartheta + a_{25}x_b + a'_z\xi \\ \dot{\theta} = (a_{33} - a_{34})\theta + a_{34}\vartheta + a_x\xi \\ \dot{\vartheta} = \omega_z \end{cases} \tag{2}$$

The definitions for all the symbols in formula 2 can be found in reference [2].

The transfer function can be derived from the above state equation, and this is a non-minimum phase system, as described in formula 3, where $a_z < 0, a_{34} > 0, a_{24} > 0, a_x > 0$.

$$G_\xi^\vartheta = \frac{a_z(S + a_{34}) - a_x a_{24}}{S[S^2 + a_{34}S - a_{24}]} \tag{3}$$

Design of Simple Backstepping and Integral Compound Controller

Define an error variable as $z_1 = \vartheta - \vartheta^*$,Then we get

$$\dot{z}_1 = \dot{\vartheta} - \dot{\vartheta}^* = \omega_z \tag{4}$$

Design the desired acceleration signal ω_z^d as

$$\omega_z^d = -k_1 z_1 - k_4 \int z_1 dt \tag{5}$$

Then its derivative can be written as

$$\dot{\omega}_z^d = -k_1\dot{z}_1 = -k_1\omega_z \tag{6}$$

Define an angular velocity error variable as $z_2 = \omega_z - \omega_z^d$,Then we get

$$\dot{z}_2 = \dot{\omega}_z - \dot{\omega}_z^d = -a_{24}\theta + a_{24}\vartheta + a_{25}x_b + a'_z\xi - \dot{\omega}_z^d \tag{7}$$

Choose an auxiliary control variable as

$$u = a_{25}x_b + a'_z\xi \tag{8}$$

Then design the backstepping control law as

$$u = -(-a_{24}\theta + a_{24}\vartheta) - k_1\omega_z - k_2 z_2 - k_3\int z_2 dt \tag{9}$$

The flutter is difficult to eliminate due to integral control.

Fuzzy laws are established to design proper backstepping parameters k_1 and k_2 Choose the initial gain values as $k_{10} = 5$, $k_{20} = 25$. If $|e| > 0$, then k_{1a} and k_{2a} should increase the value.

And we design

$$k_1 = k_0 + k_{1a}, \quad k_2 = k_{20} + k_{2a} \tag{10}$$

Design the fuzzy system with input e, and output k_{1a} and k_{2a}.

Definitions of fuzzy set for inputs and outputs are described as the following.

$e = \{NB \quad NM \quad ZO \quad PM \quad PB\}$

$k_{1a} = \{NB \quad NM \quad ZO \quad PM \quad PB\}$

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And then define a medium error value as $e_m = 5/57.3$, medium value $k_{1am} = 30$, and $k_{2am} = 140$.

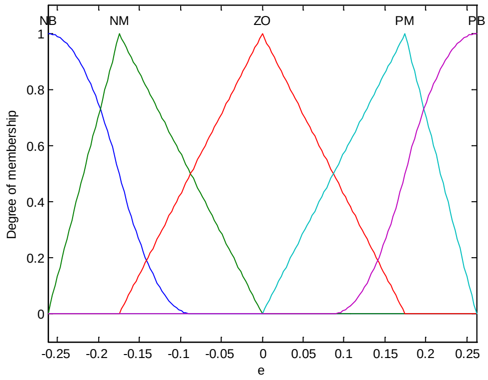

Figure 1 Membership of error

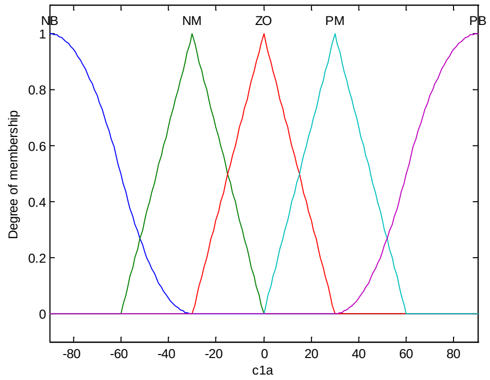

Figure 2 Membership of c_{1a}

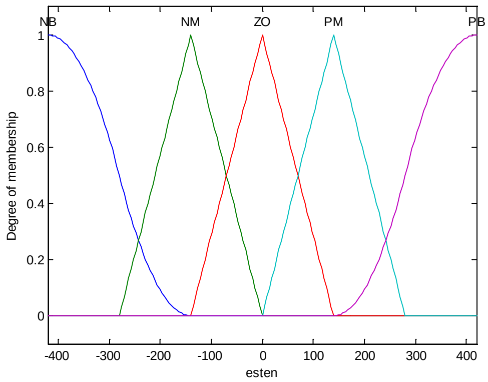

Figure 3 Membership of ε_{1a}

Define the fuzzy law of Δk_1 and Δk_2 as the following:

R1: IF $|e|$ is PB Then Δk_1 is PB and Δk_2 is PB

R2: IF $|e|$ is PM Then Δk_1 is PM and Δk_2 is PM

R3: IF $|e|$ is ZO Then Δk_1 is ZO and Δk_2 is ZO

Simulation Analysis

To testify the rightness of the above fuzzy backstepping integral control strategy, Matlab software is used to do the numerical simulation analysis. And the model parameter can see below table 1.

Table 1 Kinetic coefficients

a_{24}	a_{25}	a_{34}	a_{37}	a_x	a_z (a'_z)
829.0773	-19.1620	2.3230	0.0013	0.0289	-12.8979

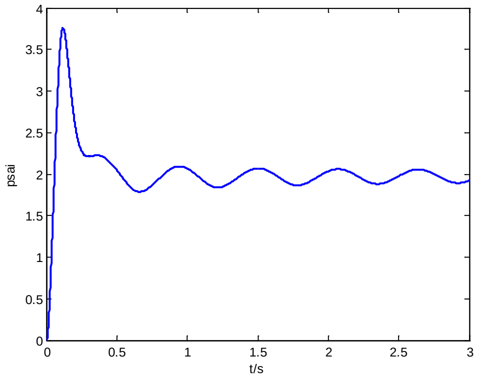

Figure 4 Curve of attitude angle

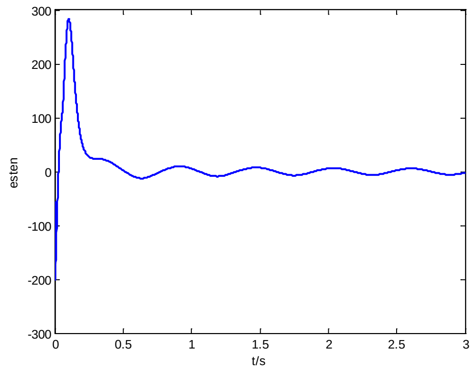

Figure 5 Curve of jet control

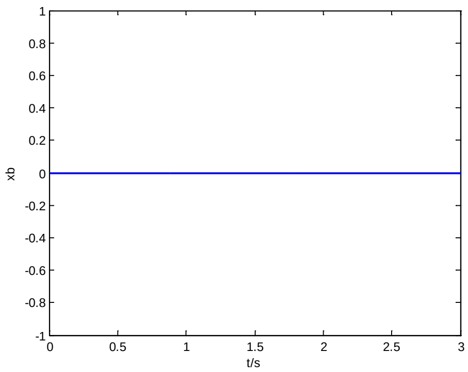

Figure 6 Curve of mass control

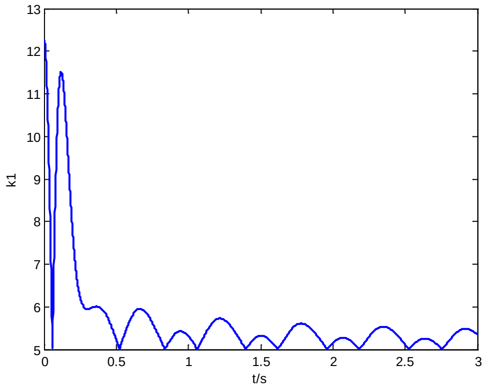

Figure 7 Curve of K1

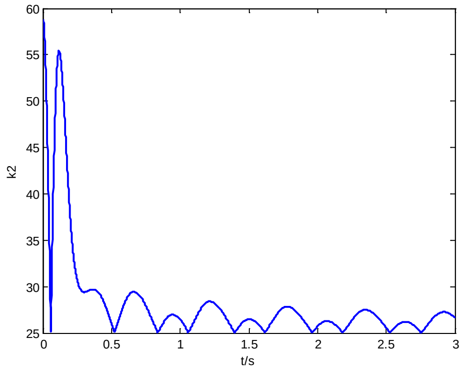

Figure 8 Curve of K2

The figure 4 shows the attitude angle of saucer shaped aircraft, and because of the integral control, there exist overshoot and oscillations. And figure 5 shows the jet control and figure 6 shows the mass control. So here we only used jet control and mass control was set to be zero. And figure 7 and figure 8 shows the fuzzy adjustment of backstepping integral compound control gains. And we found that the fuzzy control can not increase the damping of the system, so too much integral control can cause big oscillations and it can not be solved by fuzzy control strategy.

Conclusions

In this paper, the longitudinal channel of the saucer-shaped aircraft is simplified to obtain the linear equation, and then the attitude and angular velocities of the aircraft are controlled by the fuzzy backstepping algorithm. The simulation results show that the fuzzy backstepping algorithm has high anti-interference performance, but the steady-state accuracy is not enough. Therefore, on the basis of fuzzy backstepping, a fuzzy backstepping integral compound controller is constructed by the use of integral. Simulation results of the controller show that the fuzzy backstepping integral control algorithm can improve the system's steady-state accuracy while guarantee the anti-interference performance at the same time.

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