A Simple Backstepping Control Method for Saucer-shaped Aircraft

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Keywords: Backstepping Control; Saucer-shaped Aircraft, Stability, Lyapunov function

Abstract. In this paper, a simple backstepping control method is designed for a class of simplified linear model of saucer-shaped aircraft. This method can solve the non-minimum phase problem for the control of the aircraft by means of matching the two gains. The advantage of this method is that there is no need to use integral control to obtain better control precision, thus reducing the complexity of the control algorithm. The effectiveness of the proposed method is verified by detailed simulation analysis.

Introduction

The saucer-shaped aircraft is designed with the wing and body fused to avoid the additional resistance caused by the interference from fuselage and wing, and this design can provide the lift for the machine, but cannot utilize the traditional control method of heading the rudder by deflection control [1-3]. At present, many scholars have proposed a variety of control methods, such as the combination of moving mass control and thrust vector control, but this control method faces the difficulty in coordinating the two actuators to achieve the best maneuver flight [4]. The design method of the controller is presented by using the variable structure method in the literature [5], but this method can only be used for the input signal with certain rules. The method in literature [6-10] applies Lyapunov optimization controller, but it is difficult for realization because it has to design the controller from the views of information related with sub-systems. In this paper, a simple backstepping control method is proposed based on the simplified longitudinal channel of saucer-shaped aircraft. Backstepping control is generally used for non-linear system, and it aims at stable control laws by constructing a Lyapunov function, thus solving the control difficulty for saucer-shaped aircraft in non minimum phase systems.

Model Description

According to literature [4], the 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 [7]. 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 [4], 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 [4].

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 $a_z < 0, a_{34} > 0, a_{24} > 0, a_x > 0$.

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

Simple Sliding Mode Controller Design

Define an error variable as in literature [8-10]: $z_1 = \vartheta - \vartheta^*$. Then $\dot{z}_1 = \dot{\vartheta} - \dot{\vartheta}^* = \omega_z$.

Design the desired acceleration signal ω_z^d as:

$$\omega_z^d = -k_1 z_1 \tag{4}$$

Then we get the derivative as

$$\dot{\omega}_z^d = -k_1\dot{z}_1 = -k_1\omega_z \tag{5}$$

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

$$\dot{z}_2 = \dot{\omega}_z - \dot{\omega}_z^d = -a_{24}\theta + a_{24}\vartheta + a_{25}x_b + a'_z\xi - \dot{\omega}_z^d \tag{6}$$

Choose an auxiliary control variable as

$$a_{25}x_b + a'_z\xi = u \tag{7}$$

Then design the backstepping control law as

$$u = -(-a_{24}\theta + a_{24}\vartheta) - k_1\omega_z - k_2 z_2 \tag{8}$$

According to Lyapunov stability theorem, it is easy to prove the system is stalbe.

Simulation Analysis

To testify the rightness of the above simple backstepping control strategy, we use Matlab software to do the numerical simulation analysis. And the model parameter can see below table 1, and we choose control parameter as k_1=15, k_2=85, and the simulation results are shown in figure 1 and figure 2.

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

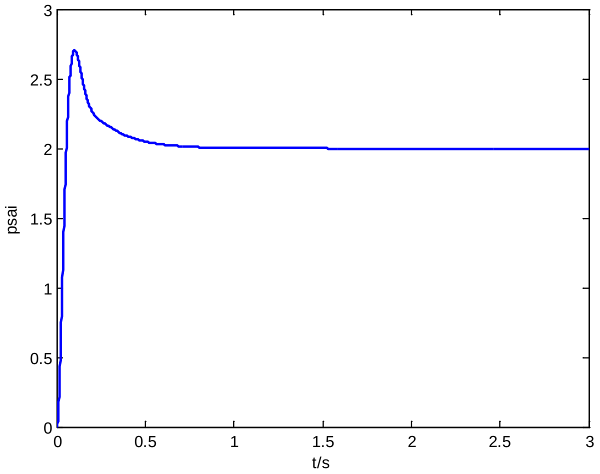

Figure 1 Curve of attitude angle of aircraft

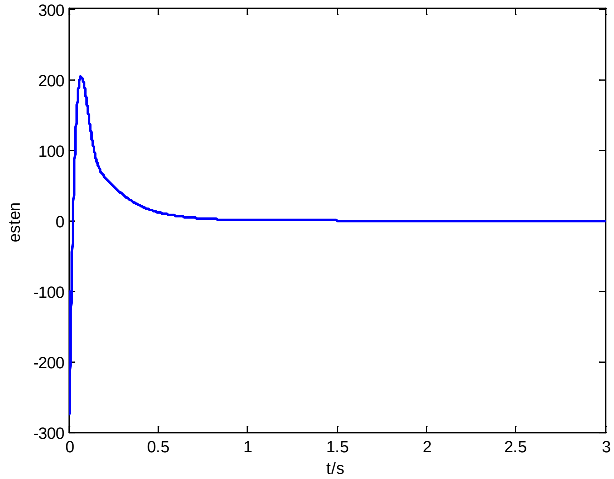

Figure 2 Curve of control

The figure 1 shows that the proposed method is very effective and response of the system is very quick. The rise time is less than 0.2s, which is very fast for saucer shaped aircraft. And the overshoot is also can be accepted by engineers. Figure 2 shows the control of ξ, where we set x_b is equal to zero.

Conclusions

In this paper, the backstepping control algorithm is adopted to realize the stable control of the longitudinally simplified model for the saucer-shaped aircraft by the matching the two gains. From the simulation results, it can be concluded that the backstepping control can obtain high control precision and fast dynamic performance, and what's more, the backstepping control structure is simple and feasible for practical application due to the unnecessarily use of integral control.

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