

Position Control for Closing Phase of ARD

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Abstract. Adaptive sliding mode control (ASMC) is used to achieve high precision position control for the closing phase of autonomous rendezvous and docking (ARD). The nonlinear relative dynamic equation is given; the gain is adjusted according to the adaptive law. If the error is small, the chattering is reduced, the precision is improved. The stability is proved. To decouple the system, time sharing strategy is used. The simulation results show ASMC has higher precision than SMD, and is faster than SMD.

1. Introduction

Automatic rendezvous and docking (ARD) is used spreadly with the tasks of spatial assembly, on-orbit service and deep space exploration. The ARD includes homing, flying-around and closing phases [1, 2]. Each phase has its special focus such as energy, safety and accuracy.

The closing phase is the last phase of ARD. The relative distance between the target and the chaser is hundreds of meters. The objective of this phase is to achieve accurate and safety docking. The ideal trajectory is straight-line, so the controlled variables include the relative distance and velocity. But the system is nonlinear with uncertain factor and disturbance. The control objective is not easy to realize.

Sliding mode control (SMC) is robust for nonlinear system [1-5], its fit for ARD [6-9]. But the shortcoming of SMC is chatter. As we known, the greater the gain, the better the robustness, and the worst the chatter problem, so the robustness and the chatter are contradictory. In the closing phase, the relative position and velocity of the system are small, so the robustness problem is not prominent. To realize ARD, the chattering problem which can affect the accuracy must be solved.

To solve the chattering problem, the gain of the SMC should be adjusted online [10]. Based on this principle, adaptive sliding mode control (ASMC) is used to obtain the flexible gain.

In this paper, the first chapter is to build the relative dynamic model. The second chapter is to introduce the designation procedure of the controller. The third chapter is to show the simulation results. And the last chapter is the conclusion.

2. Dynamic model

Assume the target works at uniform motion, the chaser could transfer orbit several times, fly-around the target and approach to the target. So the target and the chaser have independent motion. To study the ARD, the relative motion of the spacecrafts should be built.



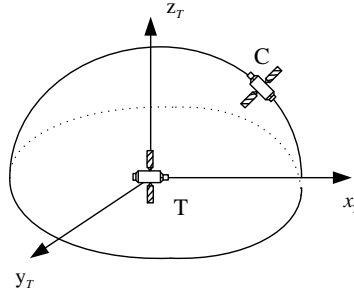


Figure 1. The coordinate of the closing phase

The relative position between the chaser and the target is shown in Figure.1. $T_{x_T y_T z_T}$ is the target orbit frame and its centre is at the origin of the target. Positive x_T is along the velocity vector direction, positive y_T is along and away from the Earth's centre and z_T axis is along the normal of target orbit. Under ideal attitude control system, $T_{x_T y_T z_T}$ is the target body frame too.

The Hill equation is used comprehensively in ARD[11]. It is described as following:

$$\begin{cases} \ddot{x} - 2\omega\dot{y} = a_x \\ \ddot{y} - 3\omega^2 y + 2\omega\dot{x} = a_y \\ \ddot{z} + \omega^2 z = a_z \end{cases} \quad (1)$$

where x, y, z are the relative distance. $\dot{x}, \dot{y}, \dot{z}$ are the relative velocity. ω is the angular velocity of target orbit. a_x, a_y, a_z are acceleration components acting on the chaser.

3. The controller designation

Because the gain of the sliding mode control is the key factor which is impact on the precision of the system, so the adaptive sliding mode control is to adjust the gain of the SMC.

3.1. Time sharing control

As seen from (1), three channels x, y, z are coupled. To decouple the system, time sharing control strategy is used. The control procedure is as following: Firstly, command $\dot{x} = 0$, then the impact of x on y is disappeared. Secondly, command $y = 0, z = 0$, clear away the impact of y, z on x . Lastly, command $x = 0$ to docking successfully.

3.2. SMC

The expression of switching function is

$$s = e + \dot{e} \quad (2)$$

where $e = 0 - x = -x$ is the error.

The control law of SMC can be designed by the following [12]

$$a_x = -\dot{x} - 2\omega\dot{y} - k_x \text{sign}(s_x) \quad (3)$$

$$a_y = -\dot{y} - 3\omega^2 y + 2\omega\dot{x} - k_y \text{sign}(s_y) \quad (4)$$

$$a_z = -\dot{z} + \omega^2 z - k_z \text{sign}(s_z) \quad (5)$$

Where k_x, k_y, k_z are the gain of x,y,z channel.

3.3. ASMC

The switching function is linear just like (2), and the control law are like (3)~(5), but the value of k_x, k_y, k_z are changed according to the law[10]

$$\dot{k}_i = \begin{cases} \lambda_i \text{sign}(|e_i| - \varepsilon_i), & k \geq \mu_i \\ \mu_i, & k < \mu_i \end{cases} \quad (6)$$

Where $\lambda_i > 0$ is the change rate of gain, $\varepsilon_i > 0$ is threshold constant, μ_i is the minimum value of the gain.

3.4. Stability analysis

According to the above analysis, the control law is designed as constant rate approach law, so if the Lyapunov function is designed as $v = 0.5s^2$, then, $\dot{v} = -ks \cdot \text{sign}(s)$. Obviously, \dot{v} is negative definite. So the system is stability.

4. Simulation results

If the initial relative position and velocity of chaser and target are shown in Table1.

Table 1. The initial value of the system

x[m]	y[m]	z[m]	\dot{x} [m/s]	\dot{y} [m/s]	\dot{z} [m/s]
0	35	-35	-1	-10	-8

The simulation has two cases according to the existence of the time sharing control strategy.

4.1. Without the time sharing strategy

Using the dynamic equation (1), and the SMC is (2) ~ (5), the relative parameters value in SMC are $\gamma_x = 25$, $\gamma_y = 10$, $\gamma_z = 5$. The results are shown in Figure.2~Figure5.

Figure.2~Figure.4 show ASMC is faster than SMC, and ASMC has higher precision than SMC. Figure.5 is shown the flight path with SMC and ASMC. The flight path is not straight line.

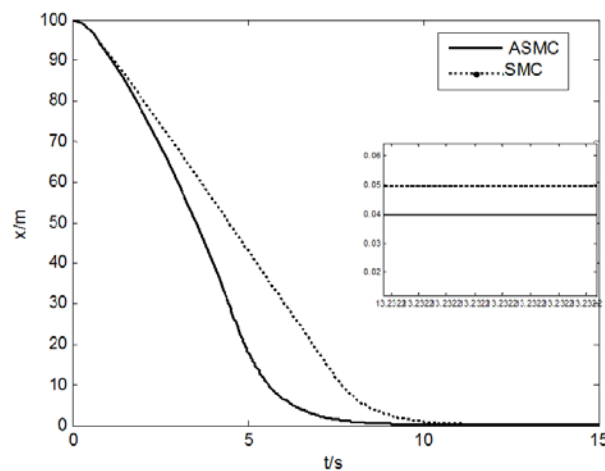


Figure 2. The change of x

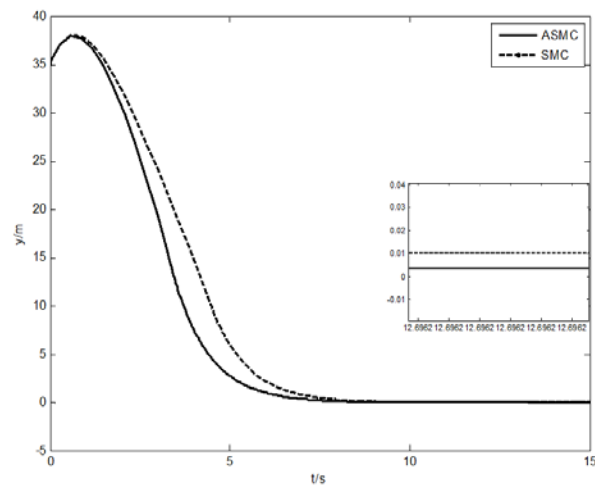


Figure 3. The change of y

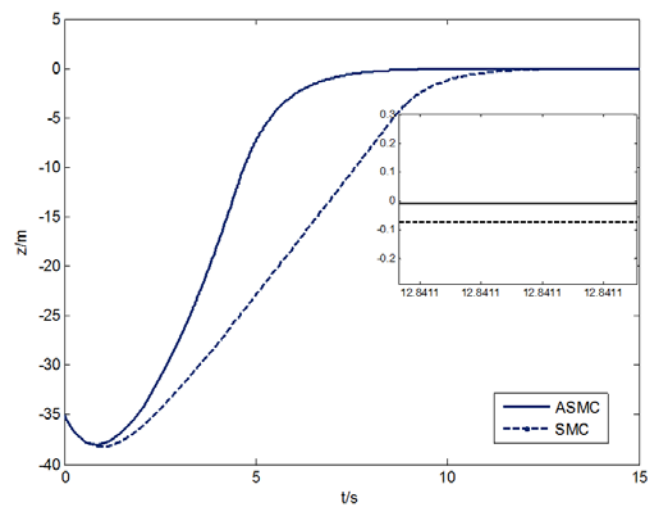


Figure 4. The change of z

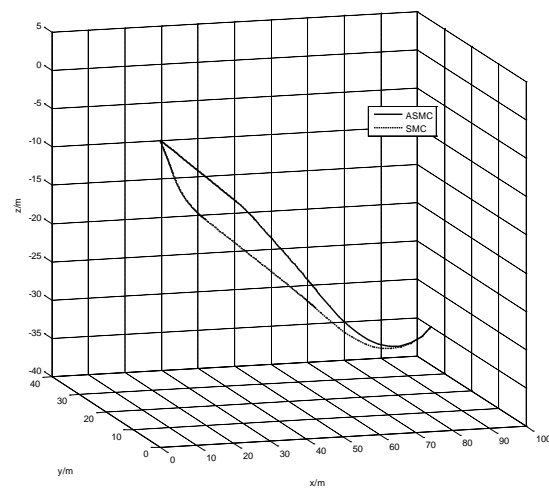


Figure 5. The flight path of ARD

4.2. With time sharing strategy

Using the dynamic equation (1), and the ASMC is (6)~(9), the parameters value in ASMC are as following: $k_{x0} = 25$, $k_{y0} = 10$, $k_{z0} = 2$, which is equal to the gain of SMC. The change rate of the gain is $\lambda_x = 5$, $\lambda_y = 2$, $\lambda_z = 2$, $\mu_i = 0.1$, $\varepsilon_i = 0.02$.

Using time sharing strategy, the simulation results are shown in Figure.6~Figure.9. Figure.6 show the distance of z is vanished within 10 seconds. Figure.7 show the distance of y is vanished between 12s and 20s. Figure.8 show the distance of x is vanished after 20s. All the above show the ASMC is faster than SMC. And the precision of ASMC is higher than SMC. Figure.9 is the flight path of ARD. The flight path is straight line which is according to the designation procedure.

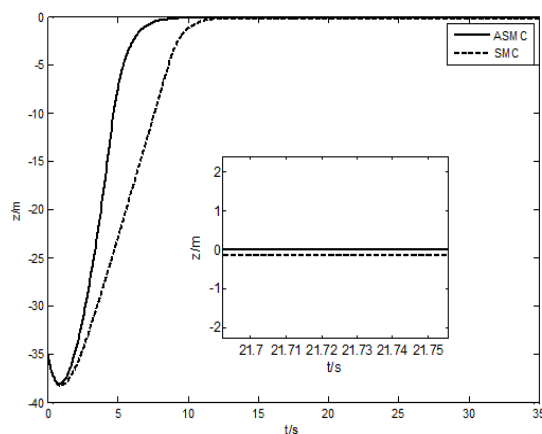


Figure 6. The change of z

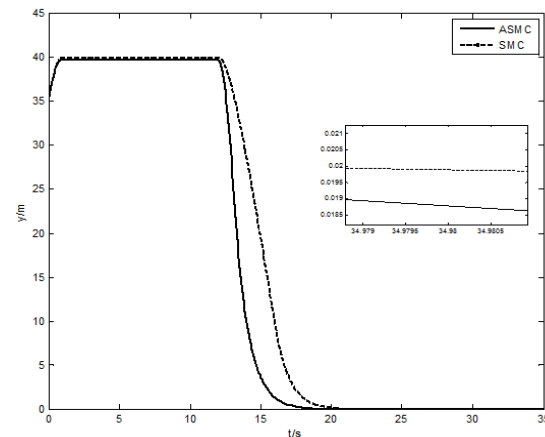


Figure 7. The change of y

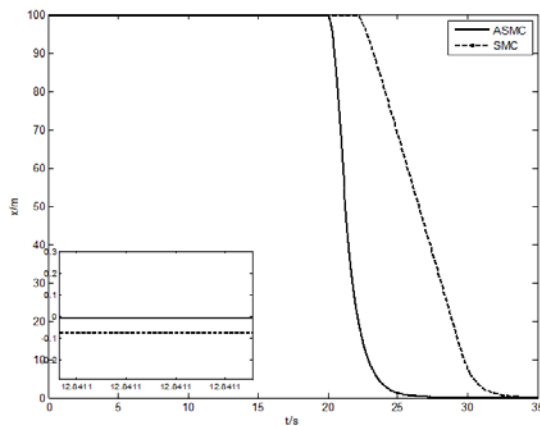


Figure 8. The change of x

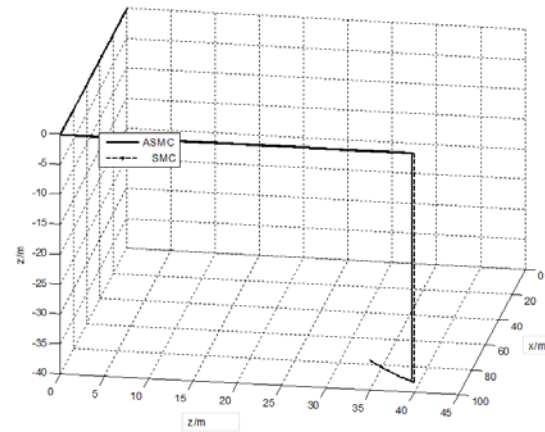


Figure 9. The flight path of ARD

5. Conclusion

Using ASMC, the control precision of the closing phase is improved. The gain of SMD is adjusted by the adaptive law, the method is easy to complete. Using time sharing strategy, the control performance is agree with the expect effect.

6. Acknowledgement

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7. References

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