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Adaptive Terminal Sliding Mode Control for Reentry Vehicle Based on Nonlinear Disturbance Observer

Binghe An[1,2], Bo Wang[1,2], Yongji Wang[1,2] (Member, IEEE), Lei Liu[1,2]
[1] School of Artificial Intelligence and Automation, Huazhong University of Science and Technology, Wuhan, 430074, China
[2] National Key Laboratory of Science and Technology on Multispectral Information Processing
Corresponding author: Bo Wang(e-mail: wb8517@hust.edu.cn).

ABSTRACT The movement of reentry vehicle is disturbed by the atmospheric environment and changes of aerodynamic parameters. In this paper, an adaptive terminal sliding mode control method based on nonlinear disturbance observers is proposed, which is used to control the attitude of the reentry vehicle. Firstly, the attitude control system is divided into an attitude angular control loop and an angular velocity control loop. Then, novel finite time convergence nonlinear disturbance observers are designed to estimate lumped disturbances. In the design of control law, the super-twist algorithm is used to make the proposed terminal sliding mode variables converge to the origin within a finite time and reduce the chattering of the controller. The estimated value of disturbance is considered in the controller to attenuate the effect of disturbances on the vehicle. Last, the algorithm proposed is applied to reentry vehicle and a good performance can be obtained. The effectiveness and superiority of the proposed algorithm is demonstrated by numerical simulations.

INDEX TERMS Reentry vehicle, Attitude control, Nonlinear disturbance observer, Terminal sliding mode, Super twist algorithm

I. INTRODUCTION

The velocity of the reentry vehicle is fast, and the flight is affected by wind disturbance, atmospheric density and change in the Earth's gravitational force[1]. The aerodynamic parameters of vehicles are time-varying because aerodynamic parameters are affected by altitude and velocity changes. As a result, the movement of the reentry vehicle has obvious nonlinearity, coupling, and uncertainty characteristics[2]. Attitude control plays an important part in the reentry vehicle control system. Achieving a precise attitude control can provide enough aerodynamic force to ensure that the vehicle can stably track guidance instructions.

The vehicle attitude control methods commonly used include auto disturbance rejection control[3], back-stepping control[4], and sliding mode control(SMC). SMC is a nonlinear control method proposed by former Soviet scholar Emelyanov. The main advantage of the sliding mode control method is that it is not sensitive to external disturbances and uncertainties[5]. With the concept of reaching law, dynamic sliding mode, and high-order sliding mode[6] being proposed, the sliding mode control theory has been further developed. Many scholars have applied the

sliding mode control method in the vehicles field. Munoz F[7] used the improved second-order sliding mode method in the attitude control problem of the quadrotors. The experiments were conducted outdoors, and noise was added during the flight of the quadrotors. Using the control law proposed, the attitude angles of the vehicle can effectively track the desired signals, although with disturbances, which proves the feasibility of the sliding mode control method in practical applications. Tian B[8] proposed a dynamic sliding variable method for the attitude tracking problem of the reusable launch vehicle. The initial sliding variable was designed which was set at the origin from the initial time, so that the arrival phase of the sliding mode control is eliminated, and the global robustness of the system is improved. By adding the relative degrees of the system, the quasi–continue high order sliding mode control laws were used for attitude control of reusable launch vehicles in[9]. However, the higher derivative of system states and the sliding mode variable need to be obtained for completing the control law. The terminal sliding mode controller(TSMC), which was proposed in[10], is a finite time control method. Due to the good dynamic characteristics of the terminal sliding mode, TSMC was

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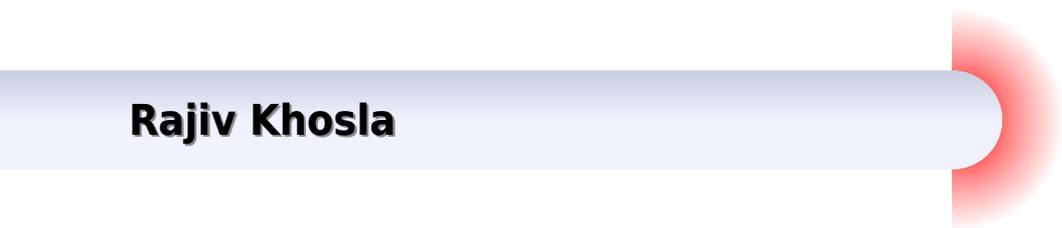
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