Accepted Manuscript

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PII: S1270-9638(17)31446-3
DOI: https://doi.org/10.1016/j.ast.2017.10.001
Reference: AESCTE 4234

To appear in: *Aerospace Science and Technology*

Received date: 8 August 2017
Revised date: 29 September 2017
Accepted date: 2 October 2017

Adaptive Backstepping Fast Terminal Sliding Mode Controller Design for Ducted Fan Engine of Thrust-Vectored Aircraft

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Abstract

In this article, a combination of backstepping control and fast terminal sliding mode control is considered for controlling a ducted fan engine of thrust-vectored aircraft subject to parameter uncertainties and external disturbances. To increase the speed of convergence of the system states to the equilibrium points or to decay state errors to zero, the fast terminal sliding mode controller is used. For the first design, to compensate for uncertainties and also incoming disturbances to the system, a new backstepping fast terminal sliding mode control (BFTSMC) is derived. At the second design, to estimate the upper bound value of the lumped uncertainty in the BFTSMC, an adaptive rule is proposed, and an adaptive backstepping fast terminal sliding mode controller (ABFTSMC) is obtained. The asymptotic global stability of the closed-loop system is proved by Lyapunov stability theorem. Various scenarios are considered; then, the designed controllers are compared with traditional sliding mode controller (SMC) and adaptive SMC (ASMC) in the presence of external disturbances. Simulation results show that the proposed controllers can have a faster transient response and higher robustness against different types of disturbances in comparison with SMC and ASMC. Some advantages of the proposed controllers are simplicity in design and implementation, improving closed-loop system stability and better tracking.

Keywords: Adaptive; sliding mode; backstepping; fast terminal; Lyapunov

1. Introduction

One of the fascinating areas in areospace industry which needs high performance in practice is the nonlinear jet aircraft system control. Vectored propulsion system of modern jet aircraft serves as a good platform for improving its high-performance capabilities, such as executing quick transition between hover, forward flight and reverse flight, as well as other aggressive flight maneuvers. One of the most important parts of some jet aircraft is ducted fan engine which is used for controlling either a thrust vectored aircraft such as F18-HARV or X-31 in forward flight mode or a vertical take-off and landing (VTOL) aircraft such as Harrier in hover mode [1].

Ducted fan engine system has been studied in a number of articles. A few references are currently available for designing and implementing robust nonlinear controllers for this special system. Jabdabaei et al. [2] proposed a receding horizon control for the planar model of a caltech ducted fan engine using control lyapunov function (CLF) approach. Wang et al. [3] presented a comprehensive nonlinear modeling and simulation analysis of a tandem ducted fan aircraft. Chadli et al. [4] designed a robust fault tolerant tracking controller for a VTOL aircraft.

The control of an industrial ducted fan aircraft presents many challenges. Ducted fan vehicles are usually unstable with complex aerodynamics and highly nonlinear and unknown terms in their mathematical model. Hence, effective controllers must be rigorously robust to deal with the uncertainties existing in the available models of the vehicle dynamics.

Nonlinear backstepping is a robust nonlinear controller which in recent years has received much attention. Backstepping control is a recursive procedure for stabilizing the origin of a strict-feedback nonlinear system [5], which is based on the Lyapunov stability theory. The idea of backstepping controller is to break a design problem for the full system into a series of design problems for lower order subsystems and then choose recursively some suitable functions as virtual control inputs for lower order subsystems of the whole system. In each step, a new virtual control law which is expressed in terms of the virtual control laws from former design steps is obtained. When the process is accomplished, a state feedback law for the main control input is obtained by means of an ultimate Lyapunov function, which is made by summing up all Lyapunov functions considered for each individual design step. Su et al. [6] proposed a backstepping controller based anti-disturbance flight for autonomous aerial refueling. Sadati et al. [7] designed a backstepping controller using neural networks for a fighter aircraft. Hu et al. [8] presented a robust adaptive backstepping control scheme for the attitude stabilization and vibration reduction of flexible spacecraft in the presence of actuator saturation.

The sliding mode controller (SMC) is a robust nonlinear controller which in recent years has been widely used for controlling nonlinear uncertain systems due to many attractive advantages, such as fast response, good transient performance and insensitivity to uncertainties [9]. This controller is based on the theory of Lyapunov, and it can favorably control the system in the presence of uncertainties and disturbances. The conventional SMC design method is comprised of two stages. First, a sliding mode surface shall be designed in a way that certain desired properties are gained by the system trajectory along the surface. Afterwards, a discontinuous control signal (switching control term) should be designed to make the system trajectories reach the sliding surface in finite time [10]. An SMC