SPACECRAFT ATTITUDE CONTROL USING ADVANCED SLIDING MODE CONTROL TECHNIQUES

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by

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To the memory of my mother

Sharda Devi

and my sister

Guddi

Certificate

This is to certify that the thesis entitled **"Spacecraft Attitude Control Using Advanced Sliding Mode Control Techniques"**, submitted by **Mr. Pyare Mohan Tiwari** to the **Indian Institute of Technology Delhi**, for the award of the degree of **Doctor of Philosophy** in Electrical Engineering, is a record of the original, bona fide research work carried out by him under our supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other university or institute for the award of any degree or diploma.

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Abstract

Attitude control system (ACS) plays a significant role in the success of a space mission. Attitude accuracy, convergence time to the desired attitude, robustness against the inertia uncertainty and external disturbances, and required control input to accomplish the target attitude are the performance criteria to evaluate the ACS efficacy.

Sliding mode control, a robust control method, has been investigated greatly for the attitude control of a spacecraft. However, chattering and asymptotic convergence are the limitations for this method. In last two decades, sliding mode control concept has been equipped with new techniques like terminal sliding mode control, integral sliding mode control, and higher order sliding mode control. These techniques are more efficient compared to the standard sliding mode control.

The objective of this thesis is to present three-axes control methods for the attitude control of a rigid spacecraft. The attitude control method should ensure high attitude accuracy, fast convergence speed, robustness against uncertainty and disturbances, and limited control energy use. To represent the attitude, an efficient attitude parameter of quaternion is adopted.

To achieve the control objectives, advanced techniques of sliding mode control are applied. In the first contribution, a finite time convergent continuous time attitude controller is presented. In this approach, a new fast terminal sliding surface is proposed and a finite time stable attitude control law is derived. In the next contribution, a non-singular fast terminal sliding surface is proposed and then equivalent control and a reaching law control are comprised to present a finite time fast converging attitude control law. Then, to eliminate the need for upper bound of uncertainty and external disturbances an adaptive gain based attitude control law is proposed. The presented control law is operating on a non-singular fast terminal sliding surface and controller gains are estimated using adaptive laws. Furthermore, higher-order sliding mode based attitude control methods are

developed to eliminate chattering and enhance robustness. In this, first a second-order sliding mode based attitude controller is formulated in fast terminal sliding mode and chattering is eliminated. Then, higher order sliding mode control laws are developed in integral sliding mode and finite time convergence, chattering elimination, and global robustness are guaranteed.

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Abbreviations and Nomenclature

Abbreviation/Symbol	Description
ACS	Attitude control system
SMC	Sliding mode control
TSM	Terminal sliding mode
FTSM	Fast terminal sliding mode
NFTSM	Non-singular fast terminal sliding mode
ANFTSM	Adaptive non-singular fast terminal sliding mode
ASFTSM	Adaptive second-order fast terminal sliding mode
ISM	Integral sliding mode
HOSM	Higher order sliding mode
SOSM	Second order sliding mode
ISSM	Integral second-order sliding mode
PD	Proportional derivative
PID	Proportional integral derivative
$\times$	Multiplication
t	Time
$\Re$	Real
R	Rotation matrix
x	State vector of the dynamical system
u	Input to the dynamical system
y	Output of the dynamical system
$f(x)$	Nonlinear vector valued function of x
$g(x)$	Nonlinear vector valued function of x
r	Order of the sliding mode
I	Identity Matrix of size 3×3
s	Sliding function