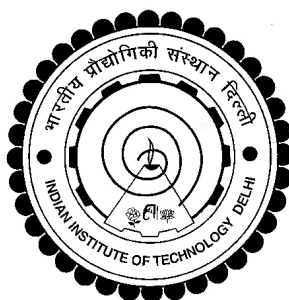


SPACECRAFT ATTITUDE CONTROL USING ADVANCED SLIDING MODE CONTROL TECHNIQUES

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JANUARY 2016

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by

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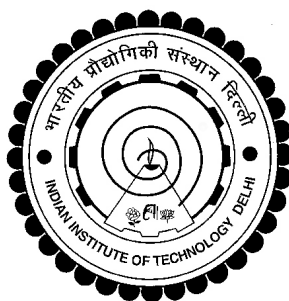
Department of Electrical Engineering

Submitted

in fulfilment of the requirements of the degree of

Doctor of Philosophy

to the



Indian Institute of Technology Delhi

January 2016

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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Acknowledgements

First of all, I would like to express my deepest gratitude to my research supervisors Dr. S. Janardhanan and Dr. M. Nabi. Without their consistent technical support, guidance and timely discussion, the work presented in this thesis could not have been possible. I also like to thank my student research committee members Prof. I. N. Kar, Prof. R. K. P. Bhatt and Prof. S. K. Saha for their constructive suggestions during the entire period of research work. I would always be grateful to the faculty and other staff members of Electrical Engineering Department of IIT Delhi for their help and support. Particularly, Mr. Jaipal Singh and Mr. Virendra need a special mention here for arranging all the computing facilities to support the research work.

I am very much indebted to the Management of Galgotias College of Engineering and Technology, Greater Noida and Amity University Uttar Pradesh for granting me necessary support required for completing the research work. I also appreciate the help extended to me by the Head and other faculty members of GCET and AUUP. I would like to extend my thanks to my friends Dr. Ashish Srivastava, Dr. J. K. Rai, Ankur Goel, and Dr. Jitender Pathak for their suggestions.

I could not have accomplished this work without the help of several individuals. Specially my lab mates N. Satyanarayan, Pankaj Mukhija, and Satnesh deserve special mention for their technical inputs and creating ambiance for the research.

A very special thank and heartfelt gratitude to my parents, brothers, sisters for their unconditional support and constant motivation. I also express my heartfelt gratitude to my wife, Manisha for maintaining her selfless support and encouragement throughout the research work. I pay gratitude to my daughter Manya and son Divyansh for missing number of affectionate days that truly belonged to them. Finally, I thank the Almighty who bestowed me with his grace and strength throughout the research work.

Pyare Mohan Tiwari

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.

Contents

Certificate	i
Acknowledgements	iii
Abstract	v
List of Figures	xi
List of Tables	xv
Abbreviations and Nomenclature	xvii
1 Introduction	1
1.1 Literature Survey	2
1.1.1 Optimal Control	3
1.1.2 Quaternion feedback PD control	4
1.1.3 Adaptive control	5
1.1.4 Sliding mode control	6
1.1.5 Terminal sliding mode control	8
1.1.6 Higher-order sliding mode control	9
1.1.7 Integral sliding mode control	10
1.2 Motivation and Objective	10
1.3 Contributions	11
1.4 Thesis outline	12

2	Preliminaries	15
2.1	Attitude Representation	15
2.1.1	Coordinate Frames	15
2.1.2	Direction Cosine Formulation	16
2.1.3	Euler Angle Formulation	17
2.1.4	Euler axis/angle	18
2.1.5	Quaternion	18
2.2	Spacecraft Attitude Equations	20
2.3	Variable Structure Control	23
2.4	Sliding Mode Control	24
2.4.1	Sliding surface design	25
2.4.2	Sliding mode control design	27
2.5	Terminal Sliding Mode	30
2.6	Integral Sliding Mode	33
2.7	Higher Order Sliding Mode	34
2.7.1	Arbitrary order sliding mode and exact robust differentiator	39
2.8	Summary	40
3	Attitude Control using Fast Terminal Sliding Mode	41
3.1	Introduction	41
3.2	Control Objective	42
3.3	FTSM Control Design	42
3.4	Simulation Results	49
3.5	Summary	51
4	Attitude Control using Non-singular Fast Terminal Sliding Mode	55
4.1	Introduction	55
4.2	Problem Formulation	56
4.3	NFTSM Control Design	56
4.4	Simulation Results	63

4.5	Summary	67
5	Attitude Control using Adaptive Non-singular Fast Terminal Sliding Mode	69
5.1	Introduction	69
5.2	Problem Formulation	70
5.3	ANFTSM Control Design	71
5.3.1	Adaptive estimate law	72
5.4	Simulation Results	75
5.5	Summary	79
6	Attitude Control using Second-order Adaptive Fast Terminal Sliding Mode	81
6.1	Introduction	81
6.2	Problem Formulation	82
6.3	Control Design	82
6.4	Simulation Results	90
6.5	Summary	93
7	Attitude Control using Adaptive Integral Higher-order Sliding Mode	97
7.1	Introduction	97
7.2	Problem Formulation	98
7.3	Control Design	99
7.3.1	Auxiliary control	101
7.3.2	Integral second-order sliding mode control design	102
7.4	Integral higher-order sliding mode control design	107
7.5	Simulation Results	109
7.6	Summary	116
8	Conclusion and Future Work	123

List of Figures

2.1	Attitude stabilization	21
2.2	Attitude tracking	23
2.3	Phase portrait of double integrator system under VSCS	24
2.4	Phase portrait of double integrator system under SMC	29
3.1	FTSM control: Quaternion and Angular velocity response for initial condition of Case 1	51
3.2	FTSM control: Sliding surface (s) response for initial condition of Case 1	51
3.3	FTSM control: Control input for initial condition of Case 1	52
3.4	FTSM control: Quaternion and Angular velocity response for initial condition of Case 2	52
3.5	FTSM control: Sliding surface (s) response for initial condition of Case 2	53
3.6	FTSM control: Control input for initial condition of Case 2	53
3.7	TSM control: Quaternion and Angular velocity for initial condition of Case 1	53
4.1	NFTSM control: Quaternion error and Angular velocity error for initial condition of Case 1	64
4.2	NFTSM control: Sliding variables for initial condition of Case 1 . . .	64
4.3	NFTSM control: Control input for initial condition of Case 1	65
4.4	NFTSM control: Quaternion error and Angular velocity error for initial condition of Case 2	65

4.5	NFTSM control: Sliding variables for initial condition of Case 2 . . .	66
4.6	NFTSM control: Control input for initial condition of Case 2	66
4.7	Unwinding NFTSM control: Quaternion error, Angular velocity error, and Control input for initial condition of Case 2	66
5.1	ANFTSM control: Quaternion error and Angular velocity error for initial condition of Case 1	76
5.2	ANFTSM control: Control input for initial condition of Case 1 . . .	77
5.3	ANFTSM control: Adaptive gain for initial condition of Case 1 . .	77
5.4	ANFTSM control: Quaternion error and Angular velocity error for initial condition of Case 2 with impulsive external disturbance and inertia uncertainty	78
5.5	ANFTSM control: Control input for initial condition of Case 2 in the presence of impulsive external disturbance and inertia uncertainty	79
5.6	ANFTSM control: Adaptive gain for initial condition of Case 2 in the presence of impulsive external disturbance and inertia uncertainty	79
6.1	ASFTSM control: Quaternion and Angular velocity for initial condition of Case 1	91
6.2	ASFTSM control: Sliding surface (s) and Sliding variable (σ) and its derivative ($\dot{\sigma}$) for initial condition of Case 1	92
6.3	ASFTSM control: Control input for initial condition of Case 1 . . .	93
6.4	ASFTSM control: Adaptive gain for initial condition of Case 1 . . .	93
6.5	ASFTSM control: Quaternion and Angular velocity for initial condition of Case 2	94
6.6	ASFTSM control: Sliding surface (s) and Sliding variable (σ) and its derivative ($\dot{\sigma}$) for initial condition of Case 2	95
6.7	ASFTSM control: Control input for initial condition of Case 2 . . .	95
6.8	ASFTSM control: Adaptive gain for initial condition of Case 2 . . .	95

7.1	ISSM control: Quaternion error and Angular velocity error for initial condition of Case 1	111
7.2	ISSM control: Sliding variables (σ) and its derivative ($\dot{\sigma}$) and Integral sliding surface (s) for initial condition of Case 1	111
7.3	ISSM control: Control input for initial condition of Case 1	113
7.4	ISSM control: Adaptive gain for initial condition of Case 1	114
7.5	IHOSM control: Quaternion error and Angular velocity error for initial condition of Case 1	114
7.6	IHOSM control: Sliding variable (σ and its derivatives ($\dot{\sigma}, \ddot{\sigma}$) and Integral sliding surface (s) for initial condition of Case 1	115
7.7	IHOSM control: Differentiator response A_{nom} for initial condition of Case 1	116
7.8	IHOSM control: Control input for initial condition of Case 1	117
7.9	IHOSM control: Adaptive gain for initial condition of Case 1	117
7.10	ISSM control: Quaternion error and Angular velocity error for initial condition of Case 2	118
7.11	ISSM control: Sliding variables (σ) and its derivative ($\dot{\sigma}$) and Integral sliding surface (s) for initial condition of Case 2	118
7.12	ISSM control: Control input for initial condition of Case 2	119
7.13	ISSM control: Adaptive gain for initial condition of Case 2	119
7.14	IHOSM control: Quaternion error and Angular velocity error for initial condition of Case 2	120
7.15	IHOSM control: Control input for initial condition of Case 2	120
7.16	IHOSM control: Adaptive gain for initial condition of Case 2	121

List of Tables

3.1	Spacecraft parameters	50
3.2	FTSM controller parameters	50
4.1	NFTSM controller parameters	63
5.1	ANFTSM controller parameters	75
6.1	ASFTSM controller parameters	90
7.1	ISSM controller and IHOSM controller parameters	110

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