

**ADAPTIVE NEURO-CONTROLLER DESIGN FOR
NANO-SATELLITE ATTITUDE CONTROL**

NORHAYATI BINTI MOHD NAZID

UNIVERSITI MALAYSIA PERLIS

2012

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**ADAPTIVE NEURO-CONTROLLER DESIGN FOR
NANO-SATELLITE ATTITUDE CONTROL**

by

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TABLE OF CONTENTS

	PAGE
THESIS DECLARATION	i
ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	xv
ABSTRAK	xviii
ABSTRACT	xix
CHAPTER 1 INTRODUCTION	
1.1 Introduction	1
1.2 Problem Statement	2
1.3 State-of-the-Art	3
1.4 Objectives of Research	5
1.5 Scope of Research	5
1.6 Thesis Guideline	6
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	9

2.2	Satellite	10
2.2.1	CubeSAT Satellite	11
2.2.2	InnoSAT Project	12
2.3	Attitude Control System	15
2.4	Problem of Satellite Attitude Control	18
2.4.1	Spin Stabilization	20
2.4.2	Three-Axes Stabilization	22
2.4.3	Gravity Gradient Stabilization	23
2.4.4	Magnetic Torque and Magnetometer	23
2.5	Artificial Neural Network	25
2.5.1	General Characteristics of ANN	26
2.5.2	Application of ANN in Control System	28
2.6	Intelligent Adaptive Control	31
2.7	Previous Work of Satellite Attitude Control	33
2.8	Summary	36
CHAPTER 3	ADAPTIVE NEURO-CONTROLLER	
3.1	Introduction	37
3.2	Artificial Neural Network	39
3.2.1	Back-Propagation (BP) Algorithm	41
3.2.2	Recursive Least Square (RLS) Algorithm	43
3.3	Adaptive Neuro-Controller	46

3.3.1	Model Reference Adaptive Control (MRAC)	47
3.3.2	Internal Model Adaptive Control (IMAC)	53
3.4	Three Axes InnoSAT System with Cross Coupling Effect	59
3.5	The Simulation of Y-Thompson Spin Rate	61
3.6	Basic Proportional, Integral and Derivative (PID) Controller	64
3.7	Summary	65
CHAPTER 4	RESULTS AND DISCUSSIONS	
4.1	Introduction	67
4.2	Simulation Result for ANC based on MRAC Scheme for Three Axes Problem	70
4.2.1	Performance Analysis of ANC based on MRAC Scheme	71
4.2.2	Performance Comparison of ANC based on MRAC Scheme for Three Axes Problem	74
4.3	Simulation Result for ANC based on IMAC Scheme for Three Axes Problem	87
4.3.1	Performance Analysis of ANC based on IMAC Scheme	87
4.3.2	Performance Comparison of ANC based on IMAC Scheme for Three Axes Problem	91
4.4	Performance Comparison between ANCs and PID Controller	102

4.5	Simulation Result of ANC with Cross Coupling Effect	121
4.6	Simulation Result of Y-Thompson Spin	130
4.7	Conclusion	137
CHAPTER 5	CONCLUSION AND FUTURE WORK	
5.1	Conclusion	137
5.2	Future Work	140
REFERENCES		142
LIST OF PUBLICATIONS		151

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LIST OF TABLES

NO.		PAGE
4.1	Analysis of number of hidden nodes for three axes InnoSAT system using ANC based on MRAC trained by BP algorithm	71
4.2	Analysis of number of hidden nodes for three axes InnoSAT system using ANC based on MRAC trained by RLS algorithm	73
4.3	Performance Analysis for ANC based on MRAC scheme using BP algorithm and RLS algorithm	78
4.4	Analysis of number of hidden nodes for three axes InnoSAT system using ANC based on IMAC trained by BP algorithm	88
4.5	Analysis of number of hidden nodes for three axes InnoSAT system using ANC based on IMAC trained by RLS algorithm	90
4.6	Performance Analysis for ANC based on IMAC scheme using BP algorithm and RLS algorithm	93
4.7	Performance Analysis for ANCs and PID Controller	104
4.8	MSE for ANCs and PID Controller with unity gain	106
4.9	MSE for ANCs and PID Controller with varying gain	109
4.10	MSE for ANCs and PID Controller with measurement noise	112
4.11	MSE for ANCs and PID Controller with time delay	115
4.12	MSE for ANCs and PID Controller for all conditions	118
4.13	MSE for ANCs and PID Controller for 5% step disturbance	120

LIST OF FIGURES

NO.		PAGE
2.1	Standard CubeSAT Kit	12
2.2	External view of InnoSAT	14
2.3	Inertia Frame	15
2.4	Body frame with respect to orbit frame	16
2.5	Attitude Determination and Control System	17
2.6	Satellite move through their orbit	18
2.7	Spin Stabilization	21
2.8	Three-axis Stabilization	22
2.9	Magnetic torquer aligned with the yaw axis	25
2.10	Feed-forward multilayer neural network	27
3.1	Operation of an ANC	38
3.2	Multilayer feed-forward neural network	40
3.3	Block Diagram of an Adaptive System	47
3.4	Model Reference Adaptive Control (MRAC) structure	49
3.5	Model Reference Adaptive Control with Lead Controller	50
3.6	Internal Model Control System	54
3.7	Internal Model Adaptive Control (IMAC)	55
3.8	Block Diagram for Neural Network Model	56
3.9	Block Diagram for Inverse Neural Network Controller	57
3.10	Block Diagram of Two Axes InnoSAT with Cross Coupling Effect	60
3.11	Y-Thompson Spin for Roll Axis	62

3.12	Y-Thompson Spin for Pitch Axis	63
3.14	Y-Thompson Spin for Yaw Axis	63
3.15	Block diagram of a PID controller	64
4.1	Varying gain	68
4.2	Measurement noise at the system output	69
4.3	5% of Step disturbance of 0.05 between 300 to 600	69
4.4	MSE versus number of hidden nodes for three axes InnoSAT system using ANC based on MRAC trained by BP algorithm	72
4.5	MSE versus number of hidden nodes for three axes InnoSAT system using ANC based on MRAC trained by RLS algorithm	74
4.6	Model Reference Output with Step input response	76
4.7	Performance Comparison of ANCs based on MRAC Scheme for Step Input	77
4.8	Model Reference Output with Square Wave Input	78
4.9	Performance Comparison of ANCs based on MRAC for system with unity gain	79
4.10	Performance Comparison of ANCs based on MRAC for system with varying gain	80
4.11	Performance Comparison of ANCs based on MRAC for system with measurement noise	81
4.12	Performance Comparison of ANCs based on MRAC for system with one sample time delay	82
4.13	Performance Comparison of ANCs based on MRAC for system with influenced by all conditions	83
4.14	Simulation Result for system with addition all condition for	

	ANC trained by RLS	84
4.15	Performance Comparison of ANCs based on MRAC for system with 5% step disturbance	86
4.16	MSE versus number of hidden nodes for three axes InnoSAT system using ANC based on IMAC trained by BP algorithm	89
4.17	MSE versus number of hidden nodes for three axes InnoSAT system using ANC based on IMAC trained by RLS algorithm	91
4.18	Performance Comparison of ANCs based on IMAC for Step Input	93
4.19	Square Wave Reference Input	94
4.20	Performance Comparison of ANCs based on IMAC for system with unity gain	95
4.21	Performance Comparison of ANCs based on IMAC for system with varying gain	96
4.22	Performance Comparison of ANCs based on IMAC for system with measurement noise	97
4.23	Performance Comparison of ANCs based on IMAC for system with one sample time delay	98
4.24	Performance Comparison of ANCs based on IMAC for system with addition all conditions	99
4.25	Performance Comparison of ANCs based on IMAC for system with 5% step disturbance	101
4.26	Performance Comparison of ANCs and PID Controller for step input	103
4.27	Performance Comparison of ANCs and PID Controller for	

	system with unity gain	105
4.28	(a) The zoom out of the output response in Figure 4.27, (b) Error plot of the zoom out response in (a)	106
4.29	Performance Comparison of ANCs and PID Controller for system with varying gain	108
4.30	(a) The zoom out of the output response in Figure 4.29, (b) Error plot of the zoom out response in (a)	109
4.31	Performance Comparison of ANCs and PID Controller for system with measurement noise	111
4.32	(a) The zoom out of the output response in Figure 4.31, (b) Error plot of the zoom out response in (a)	112
4.33	Performance Comparison of ANCs and PID Controller for system with one sample time delay	114
4.34	(a) The zoom out of the output response in Figure 4.33, (b) Error plot of the zoom out response in (a)	115
4.35	Performance Comparison of ANCs and PID Controller for system with the combination all conditions	117
4.36	(a) The zoom out of the output response in Figure 4.35, (b) Error plot of the zoom out response in (a)	118
4.37	Performance Comparison of ANCs and PID Controller for system with 5% step disturbance	120
4.38	Simulation Result of the system with cross coupling for Step Input	123
4.39	Simulation Result of the system with cross coupling for unity gain	124

4.40	Simulation Result of the system with cross coupling for varying gain	125
4.41	Simulation Result of the system with cross coupling for measurement noise	126
4.42	Simulation Result of the system with cross coupling for time delay	127
4.43	Simulation Result of the system with cross coupling for addition all operating conditions	128
4.44	Simulation Result of the system with cross coupling for 5% step disturbance	129
4.45	Simulation Result for system with unity gain	131
4.46	Simulation Result for system with varying gain	132
4.47	Simulation Result for system with measurement noise	133
4.48	Simulation Result for system with one sample time delay	134
4.49	Simulation Result for system with all condition	135
4.51	Simulation result for system with 5% step disturbance	136

LIST OF ABBREVIATIONS

GPS	Global Positioning System
ACS	Attitude Control System
ADCS	Attitude Determination and Control System
ANC	Adaptive Neuro-Controller
AI	Artificial Intelligent
MRAC	Model Reference Adaptive Control
IMAC	Internal Model Adaptive Control
BP	Back-Propagation
RLS	Recursive Least Square
NN	Neural Network
PID	Proportional, Integral, Derivative
FLS	Fuzzy Logic System
L.E.O	Low Earth Orbit
H.E.O	High Earth Orbit
P-POD	Poly-Pico Satellite Orbital Deplorer
InnoSAT	Innovative Satellite
ANN	Artificial Neural Network
MLP	Multi Layered Perceptron
SISO	Single Input Single Output
OBC	Onboard Computer
MSE	Mean Square Error
SSE	Sum Square Error

LTI	Linear Time-Invariant
MIT	Massachusetts Institute of Technology
NARMAX	Non-linear Auto-Regressive Moving Average with exogenous input
IM	Internal Model
FFNN	Feed-Forward Neural Network
INN	Inverse Neural Network
MIMO	Multiple Input Multiple Output

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LIST OF SYMBOLS

F	Force
m	Mass
a	Acceleration
Φ	Angle of roll axis
θ	Angle of pitch axis
Ψ	Angle of yaw axis
X	Roll axis
Y	Pitch axis
Z	Yaw axis
t	time
n_i	Input node
n_h	Hidden node
$F(\bullet)$	activation function
$\hat{y}_l(t)$	output of the l -th neuron
n_o	number of output nodes
$v(t)$	Input of MLP network
$\hat{y}(t)$	Output of MLP network
$y(t)$	Actual output
$\varepsilon(t)$	prediction error
w	weight
b	threshold
α_w	Momentum of weight

α_b	Momentum of threshold
η_w	learning rates of weight
η_b	learning rates of threshold
$\rho_i^k(t)$	error signal of the i -th neuron of the k -th layer
$\Delta w_{ij}^k(t)$	Change of weight
$\Delta b_{ij}^k(t)$	Change of threshold
$\rho^m(t)$	error signal at the output node
$\hat{\theta}(t)$	vector of controller parameters
$P(t)$	covariant matrix
$\varphi(t)$	information vector that consists of the controller inputs
$\lambda(t)$	forgetting factor
λ_0	initial forgetting factor
$\Psi(t)$	gradient of the one step ahead predicted output
$r(t)$	reference signals input
$y_m(t)$	output of reference model
$y(t)$	system output
e	error signal
a_m	model parameters
b_m	model parameters
$u(t)$	system input
$\Sigma e(t)$	integral error
$y_n(t)$	neural network model output
$r^*(t)$	corrected setpoint for the IM

e_{IM}	error signal of IM
$v_i(t)$	input vector for INN
$u_s(t)$	PD stabilizer
$u_d(t)$	internal disturbance of the InnoSAT system
T_o	orbital rate time of the InnoSAT
g	gravitational attraction at Earth's surface
R	radius of Earth
r	radius of orbit
k_p	proportional gain
k_i	integral gain
k_d	derivative gain

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Reka Bentuk Pengawal Mudah Suai Neuro Untuk Kawalan Sikap Nano-satelit

ABSTRAK

Motivasi projek ini adalah untuk memperkenalkan teknologi kawalan kapal angkasa ke dalam pendidikan universiti dan untuk membangunkan pembinaan satelit di dalam negara bagi meletakkan negara setaraf dengan negara maju yang lain. Tujuan kajian ini adalah untuk memajukan skim kawalan tiga paksi bagi penstabilan sistem nano satelit iaitu Satelit Inovatif (InnoSAT). Pengawal Mudah Suai Neuro (ANC) telah banyak digunakan sebagai pengawal dalam banyak aplikasi seperti dalam robotik, sistem kuasa, industri dan lain-lain. Terdapat banyak aplikasi ANC dalam pengawalan sikap kawalan satelit yang dicadangkan telah berjaya dilaksanakan. Sehubungan dengan ini, empat kaedah kawalan sikap nano satelit menggunakan dua skim kawalan berbeza dan menggunakan dua algoritma berbeza telah diperkenalkan dalam kajian ini. Kawalan tersebut adalah ANC berdasarkan skim model kawalan rujukan mudah suai (MRAC) dilatih oleh algoritma perambatan balik (BP), ANC yang berdasarkan atas skim MRAC dilatih oleh algoritma kuasa dua terkecil berulang (RLS), ANC, berdasarkan skim model kawalan dalaman mudah suai (IMAC) dilatih oleh algoritma BP dan ANC berdasarkan skim IMAC dilatih oleh algoritma RLS. Dua skim kawalan berbeza ini digunakan untuk ANC mengubah tindakbalas keluaran InnoSAT bagi mengikuti sasaran yang dikehendaki. Dalam kajian ini, algoritma BP dan algoritma RLS digunakan sebagai mekanisme penyelarasan untuk mengemaskini parameter ANC. Satu rangkaian perseptron berbilang lapisan (MLP) telah terbukti mampu untuk menghampiri fungsi sebenar secara berterusan sehingga ketepatan tertentu. Ia adalah teknik yang sangat sesuai dalam disiplin sistem kawalan, terutama apabila sistem terkawal mempunyai ketidakpastian yang besar dan tidak kekeliruan yang kuat. Satu rangkaian MLP digunakan untuk ANC dalam penyelidikan ini. Reka bentuk ANC dimulakan dengan mereka bentuk ANC berdasarkan skim MRAC menggunakan algoritma BP. Kemudian, ANC berdasarkan MRAC menggunakan algoritma RLS direka dan prestasi bagi kedua-dua ANC berdasarkan MRAC dibandingkan dari segi kelajuan penumpuan dan kecapahan yang mungkin dalam keadaan tertentu. Reka bentuk itu diteruskan dengan mereka bentuk ANC berdasarkan skim IMAC dengan menggunakan algoritma BP dan bahagian terakhir rekabentuk ialah mereka bentuk ANC berdasarkan skim IMAC menggunakan algoritma RLS. Prestasi bagi kedua-dua ANC berdasarkan skim IMAC juga dibandingkan berdasarkan tempoh kelajuan penumpuan dan kecapahan yang mungkin dalam keadaan tertentu. Keputusan simulasi bagi semua ANC menunjukkan bahawa ANC menggunakan algoritma RLS mempunyai kelajuan penumpuan yang lebih cepat berbanding dengan ANC yang dilatih oleh algoritma BP. ANC berdasarkan MRAC dan ANC berdasarkan IMAC yang terbaik dibandingkan dengan pengawal kadaran, kamiran dan terbitan (PID) yang lazim. Simulasi yang telah dilaksanakan menggunakan beberapa masukan rujukan iaitu unit langkah, gelombang persegi dan Y-Thompson. Keputusan simulasi dikemukakan dan tindakbalas keluaran menunjukkan bahawa ANC berdasarkan MRAC boleh diterima pakai, walaupun sistem InnoSAT terdedah kepada gandaan yang berubah, pengukuran hingar, masa lengah dan gangguan. Kemudian, ANC berdasarkan skim MRAC disimulasikan dengan sistem gandaan merentasi dua paksi dan keputusan simulasi menunjukkan bahawa sistem InnoSAT adalah stabil. Dalam simulasi terakhir, ANC diuji dengan menggunakan sikap rujukan masa nyata iaitu rujukan Y-Thompson. Hasil kajian menunjukkan bahawa ANC berdasarkan skim MRAC boleh menstabilkan sistem InnoSAT walaupun sistem terdedah kepada gandaan yang berubah, pengukuran hingar, masa lengah dan gangguan.

Adaptive Neuro-Controller Design For Nano-Satellite Attitude Control

ABSTRACT

The motivation of this research is to bring the technology of spacecraft control into university education and to bring the possibility of developing our own satellite that will put us of equal standard with other developed nations. The purpose of this research is to develop the control scheme for three axes stabilization of nano-satellite system namely Innovative Satellite (InnoSAT). An adaptive neuro-controller (ANC) is applied as a controller in many application such as in robotics, power system, industries and etc. There are many successfully applications of ANC in controlling the satellite attitude control have been proposed. In this regards, four types of ANCs using two different control scheme and using two different algorithm for nano-satellite attitude control have been introduced in this research. These are ANC based on Model Reference Adaptive Control (MRAC) scheme trained by Back-Propagation (BP) algorithm, ANC based on MRAC scheme trained by Recursive Least Square (RLS) algorithm, ANC based on Internal Model Adaptive Control (IMAC) scheme trained by BP algorithm and ANC based on IMAC scheme trained by RLS algorithm. These two different control schemes are used by the ANC to adjust the output response of InnoSAT to follow the desired target. In this research, BP and RLS algorithms were used as an adjustment mechanism to update the parameters of the ANC. A multilayer perceptron (MLP) network with one hidden layer has the capability to approximate any continuous function up to certain accuracy. It is a very powerful technique in the discipline of control systems, especially when the controlled systems have large uncertainties and strong non- linearities. MLP network is used for ANC in this research. The design of ANC is initially started with design of ANC based on MRAC scheme using BP algorithm. Then, the ANC based on MRAC using RLS algorithm is designed and the performance for both ANCs based on MRAC were compared in term of convergence speed and possible divergence for certain conditions. The design is continued by designing the ANC based on IMAC scheme using BP algorithm and the last part of designing is designed the ANC based on IMAC scheme using RLS algorithm. The performance for both ANC based on IMAC scheme are also compared in term of convergence speed and possible divergence for certain conditions. The simulation results for all ANCs indicated that ANC using RLS algorithm have faster convergence speed compared to the ones trained by BP algorithm. The best ANC based on MRAC and ANC based on IMAC are compared with a conventional proportional, integral and derivative (PID) controller. Simulations have been carried out and for several reference inputs namely unit step, square wave and Y-Thompson. The simulation results are presented and the output responses show that the ANC based on MRAC performance is acceptable even in the case of the InnoSAT is subjected to varying gain, measurement noise, time delay and disturbance. Then, the ANC based on MRAC scheme is simulated with two axes cross coupling system and the simulation results show that the InnoSAT system is stable. The final simulation is tested the ANC with real time attitude reference which is Y-Thompson input reference. The results showed that the ANC based on MRAC scheme can stabilized the InnoSAT system even the system is subjected with varying gain, measurement noise, time delay and disturbance.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Aerospace is a branch of engineering that includes design and construction of a spacecraft or aircraft. Aerospace refer to a flight within the atmosphere and applying the principles of science and technology to highly sophisticated product such as space satellites. Space satellite is defined as any object either man-made or naturally occurring, which orbit around something else. For example, the moon orbits around the Earth, thus it is a satellite and the Earth orbits around the sun, thus the Earth is a satellite for the sun. Other examples of naturally occurring satellite include comets, stars, asteroids and other planets.

A man-made satellite is an extremely complicated piece of equipment that include propulsion system, power system, telemetry and command system, thermal control, superstructure, attitude control system and communication subsystem. Man-made satellites are classified by types and there are over ten main types of satellite used, include astronomical satellites, communication satellites, earth observation satellites, weather satellites, space stations and so on. Other type of satellites include those used to monitor earth from a military standpoint, and biosatellites, which may carry animals or other life forms for the purpose of research on earth life forms in space. Navigational satellites are

now popular and form a vital part of the Global Positioning System (GPS) that are now available in many cars.

1.2 Problem Statement

Attitude control is one of the key sub-systems in a satellite and a requirement for most satellites. One of the most important problems in satellite design is the attitude stabilization and control, which is the combination of mathematics, dynamics and control theory. There are a few types of attitude control systems. There are spin control where the entire satellite is spun, dual-spin control where the major portion spun while only the payload despun, three-axis active control where the major part of satellite despun, and gravity gradient control (Kyrkjebo, 2000).

After the satellite is launched and placed in its orbit, it can be tumbling at an undefined angular rate. At this time, the satellite needs to reduce the roll and yaw angular rate and align to the normal orbit. The proposed controller is necessary to maintain the satellite's stability even if the satellite is affected by interferences such as magnetic fields, solar wind and disturbance torque. These phenomena tend to disturb the satellite's attitude in addition to the unpredicted operating conditions that normally associated with noise, disturbance, delay and changing parameters.

There are many advanced control techniques that can be used to reduce the satellite attitude control problems, such as rate feedback, adaptive and predictive. Many schemes have been devised over the years including control moment gyros, reaction wheels, spin stabilization and gravity gradient stabilization. Although several control laws have been used to design the attitude control for nano-satellite (Kristin et al., 2001; Nagarajan et al.,

2008), a new approach is expected to be more robust and can be efficiently used in real-time control. To handle these difficulties, a research of designing an Adaptive Neuro-Controller (ANC) for application of attitude control for a nano-satellite is carried out. ANC offers the advantages of less sensitive to noise and nonlinear control structure. The aim of this project is to design a low cost attitude controller.

1.3 State-of-the-Art

Recently, there has been a great deal of excitement over the emergence of new techniques for the attitude control of small satellites. There are several ACS that have been developed for the small satellite in the last five years. Cheng et al. (2009) has proposed a method for the attitude stabilization of a satellite using the fuzzy controllers. In this proposed controller, two fuzzy controllers are used to supersede the classical controllers including a PI controller for pitch axis control and a PID controller for roll/yaw axis control by obtaining faster convergence time and lower steady-state error. These two fuzzy controllers are then consolidated to form one fuzzy controller. The simulation results indicated that the two fuzzy controllers can be used to supersede two classical controllers for attitude stabilization of the satellite and to obtain a faster convergence time and lower steady-state error. These two fuzzy controllers are consolidated to form one fuzzy controller successfully, and the consolidated fuzzy controller also retains performance as the author expected. The proposed controller is superior to the classical controller in that it does not require gain settings and complicated computation, making it more easily implemented on a microcomputer.

Yang et al. (2010) published a paper on fault detection and diagnosis (FDD) technique with actuators faults for the satellite attitude control system (ACS). The paper presented a robust neural network control (NNC) based on self-organizing fuzzy neural network (SFNN) and a robust strategy that can detect, isolate, and identify an unknown actuator fault in the satellite. A robust controller based on NNC has been presented in this paper which is insensitive to the disturbances. The system faults are identified by the SFNN, and the obtained estimation is used to reconfigure the control law. A neural network estimation system (NNES) was utilized after the fault is detected, which can reduce the computational complexity. The authors found that the proposed NNC is robust to disturbances and uncertainties of satellite ACS and has better performance than routine PD controller.

Nemati et al. (2010) used sliding mode control method for attitude control of a micro-satellite. The purpose of this paper is to establish a nonlinear model of a micro-satellite, utilizing thrusters and one reaction wheel. Then, the authors used sliding mode control as a control strategy to solve the problem of attitude control. The sliding mode controller is designed to effectively account for parameter uncertainty and the presence of unmodeled dynamics. With this method, it has been shown that sliding mode control designed for microsatellite attitude control is robust against uncertainties and unknown disturbances.

Guan et al. (2011) used a direct adaptive fuzzy control for the attitude stabilization control of a satellite. The direct adaptive fuzzy control acted on the controlled system and the adaptive law was derived based on the Lyapunov method. The parameters of rules and membership function in Fuzzy Logic System (FLS) can be adjusted in this method to have online adaptive ability. It was show that this controller was robust to the uncertainty of the