ADAPTIVE NEURO-CONTROLLER DESIGN FOR NANO-SATELLITE ATTITUDE CONTROL

NORHAYATI BINTI MOHD NAZID

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by

NORHAYATI BINTI MOHD NAZID
(0930610347)

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DECLARATION OF THESIS

Author's full name : NORHAYATI BINTI MOHD NAZID

Date of birth : 06 JULY 1986

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

GPS	Global Positioning System
ACS	Attitude Control System
ADCS	Attitude Determination and Control System
ANC	Adaptive Neuro-Controller
AI	Atificial 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

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

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 mekanisma 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 ketidaktentuan yang besar dan tidak kelelurusan 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.