DEVELOPMENT OF ADAPTIVE FUZZY LOGIC CONTROLLER FOR SATELLITE ATTITUDE CONTROL SYSTEM

by

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LIST OF ABBREVIATIONS

ACS	Attitude Control System
ADS	Attitude Determination System
ADCS	Attitude Determination and Control System
AFLC	Adaptive Fuzzy Logic Controller
AFPD	Adaptive Fuzzy Proportional Derivative
AFPFIFD	Adaptive Fuzzy Proportional + Fuzzy Integral + Fuzzy Derivative
AFPI	Adaptive Fuzzy Proportional Integral
AFPID	Adaptive Fuzzy Proportional Integral Derivative
AFPIFPD	Adaptive Fuzzy Proportional Integral + Fuzzy Proportional Derivative
AFRLS	Adaptive Fuzzy Recursive Least Square
AI	Artificial Intelligent
ANGKASA	National Aerospace Agency
ATSB	Astronautic Technology (M) Sdn. Bhd.
DA	Direct Action.
DISO	Double Input Single Output
ECI	Earth Coordinate Inertia
ES	Expert System
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Control
FPD	Fuzzy Proportional Derivative
FPFIFD	Fuzzy Proportional + Fuzzy Integral + Fuzzy Derivative
FPI	Fuzzy Proportional Integral
FPID	Fuzzy Proportional Integral Derivative

FPIFPD	Fuzzy Proportional Integral + Fuzzy Proportional Derivative
GPS	Global Positioning System
GUI	Graphical User Interface
HILS	Hardware-in-loop-simulation
HEO	High Earth Orbit
HI	High
InnoSAT	Innovative Satellite
IRAS	Infra- Red Astronomical Satellite
LEO	Low Earth Orbit
LO	Low
LQR	Linear Quadratic Regulator
MEO	Medium Earth Orbit
MF	Membership Function
MRAC	Model Reference Adaptive Control
MIMO	Multiple Input Multiple Output
MSE	Mean Square Error
NASA	National Aeronautics and Space Administration
NO	Normal
NE	Negative
OBC	On-Board Computer
PD	Proportional Derivative
PID	Proportional, Integral, Derivative
PFLC	Predictive Fuzzy Logic Control
P-POD	Poly-Pico Satellite Orbital Deployer
PO	Positive

RLS	Recursive Least Square
SISO	Single Input Single Output
SMC	Sliding Mode Control
SRM	Switched Reluctance Motor
UAV	Unmanned Aerial Vehicle
USM	Universiti Sains Malaysia
UTM	Universiti Teknologi Malaysia
UniMAP	Universiti Malaysia Perlis
UHF	Ultra High Frequency
UOD	Universe of Discourse
VHF	Very High Frequency
WRLS	Weighted Recursive Least Square
ZE	Zero

LIST OF SYMBOLS

x^*	defuzzified output
μ(x)	degree of membership function
x	output variable
m	number of inputs
k	number of linguistic
r	radius of orbit
ϕ	Roll angle
θ	Pitch angle
ψ	Yaw angle
X	Roll axis
Y	Pitch axis
Z	Yaw axis
t	Time
$P(t)$	covariant matrix
$K(t)$	Kalman filter
$\varphi(t)$	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
α	constant value between 100 and 10000
$r(t)$	reference input
$y_m(t)$	output of reference model
$y(t)$	plant output

$\varepsilon(t)$	prediction error
$e(t)$	error
$\Delta e(t)$	Derivative of error
a_m, b_m	Model reference parameters
$\dot{\theta}(t)$	Proportional, Integral and Derivative (PID) Error
$\hat{\Theta}(t)$	Vector of controller parameters
$u(t)$	Control signal from fuzzy controller
$\Sigma e(t)$	integral of error
$u_s(t)$	control signal from stabilizer
$u_d(t)$	constant disturbance torque
u_{pi}	output Fuzzy PI controller
u_{pd}	output Fuzzy PD controller
u_d	ouput Fuzzy D
u_p	ouput Fuzzy P
u_i	ouput Fuzzy I
T_o	orbital rate time of the InnoSAT
G or g	gravitational attraction at Earth's surface
R	radius of Earth
I	Identity matrix
K_p	proportional gain
K_i	integral gain
K_d	derivative gain
$K_p(t)$	Varying gain

Pembangunan Pengawal Ubah Suai Kabur untuk Sistem Kawalan Sikap Satelit

ABSTRAK

Pembangunan dalam memajukan ruang angkasa merupakan suatu penanda aras baru dalam menentukan kecanggihan teknologi moden bagi sesebuah negara pada masa kini. Oleh sebab itu, sebagai sebuah negara yang membangun, Malaysia juga tidak mahu ketinggalan untuk menjadi salah satu negara yang terlibat dalam meneroka bidang teknologi satelit ini. Secara amnya, satelit akan menerima gangguan daripada pelbagai fenomena yang berlaku di angkasa. Fenomena ini boleh mengganggu kedudukan satelit pada bila-bila masa dan keadaan. Oleh itu, pengawalan orientasi dan penstabilan kedudukan satelit adalah perlu dengan menggunakan sistem kawalan sikap (ACS). Projek ini mencadangkan kawalan ubah suai samar sebagai ACS satelit Inovatif (InnoSAT). Objektif projek ini adalah untuk membandingkan masa tindak balas dan prestasi pengesanan antara struktur pengawal. Parameter wacana sejagat akan ditalakan secara dalam talian oleh mekanisme pelarasan yang merupakan satu kaedah yang serupa dengan ralat PID yang boleh mengurangkan ralat antara keluaran sebenar dan keluaran rujukan model. Tesis ini juga membentangkan Model Rujukan Kawalan Suai (MRAC) sebagai skim kawalan untuk mengawal sistem berubah dengan masa di mana spesifikasi prestasi diberi dari segi model rujukan. Semua pengawal telah diuji menggunakan sistem InnoSAT dengan memasukkan pelbagai keadaan operasi yang melibatkan gangguan, gandaan berubah, pengukuran hingar dan tunda masa. Secara keseluruhannya, kajian ini mencadangkan lima struktur pengawal untuk satelit ACS. Tiga struktur terdiri daripada Tindakan Langsung dan dua struktur daripada jenis Hibrid. Pada mulanya, pengawal jenis Tindakan Langsung seperti Pengawal Ubah Suai Kabur PD, Ubah Suai Kabur PI dan Ubah Suai Kabur PID digunakan. Walau bagaimanapun, prestasi pengawal ini sedikit merosot apabila pengawal diuji dengan data sebenar iaitu data Y-Thomson. Maka, struktur hibrid seperti Ubah Suai Kabur P + Kabur I + Kabur D dan Ubah Suai Kabur Selari PI + Kabur PD pengawal dicadangkan untuk mengatasi masalah tersebut. Sebagai perbandingan, pengawal yang mempunyai prestasi terbaik akan dibandingkan dengan pengawal lain seperti Pengawal Kabur dan Pengawal Ubah Suai dengan algoritma Pemberat Rekursi Kuasa Dua Terkecil. Keputusan simulasi menunjukkan bahawa semua pengawal yang dicadangkan telah mendapat prestasi yang baik dalam mengesan masukan rujukan. Kawalan Ubah Suai Samar menunjukkan persembahan yang terbaik dengan kebolehupayaan dalam mengawal satelit berbanding dengan kawalan samar. Oleh itu, ini membuktikan bahawa Ubah Suai Kabur PI + Kabur PD merupakan pengawal yang terbaik untuk aplikasi ini. Sumbangan projek ini adalah untuk membawa Malaysia terus ke peringkat antarabangsa yang lebih maju bukan sahaja dalam penyelidikan, malahan dapat membangunkan dan mereka bentuk sistem satelit sendiri.

Development of Adaptive Fuzzy Controller for Satellite Attitude Control System

ABSTRACT

Development of space is one of the main symbols of technological progress in the modern society. Therefore, as a developing country, Malaysia not left in becoming one of the countries involved in exploring the field of satellite technology. Generally, the satellite receives interference from various phenomena that occurred in space. These phenomena can disturb the satellite position at any time and condition. Thus, it is necessary to control the orientation and maintain the stability of satellite by the attitude control system (ACS). This project proposed an Adaptive Fuzzy controller for ACS of Innovative Satellite (InnoSAT) based on Direct Action and Hybrid type controller structure. The objective of this project is to compare the time response and tracking performance among the structures of controller. The parameters of universe of discourse are tuned on-line by adjustment mechanism which is an approach similar to a PID error that could minimize errors between actual and model reference output. This thesis also presents a Model References Adaptive Control (MRAC) as a control scheme in order to control time varying systems where the performance specifications are given in terms of reference model. All the controllers have been tested using InnoSAT system with some operating conditions such as disturbance, varying gain, measurement noise and time delay. In order to study new methods used in satellite attitude control, this thesis presents five structure of controllers. Three structures are from Direct Action type and two structures are from hybrid type. At first, Direct Action type controller such as Adaptive Fuzzy PD controller, Adaptive Fuzzy PI and Adaptive Fuzzy PID have been applied. However, the performances of these controllers are slightly degraded while the controllers are tested in real data which known as Y-Thomson data. Thus, hybrid structure such as Adaptive Fuzzy P + Fuzzy I + Fuzzy D and Adaptive Parallel Fuzzy PI + Fuzzy PD controllers are proposed to overcome the problem. To compare the performance with other controller, Fuzzy and Adaptive Fuzzy controllers with Weighted Recursive Least Square Algorithm is proposed. Simulation results show that all controllers that have been proposed have a good performance. Adaptive Fuzzy controller shows the best capability and stronger robustness from Fuzzy controller. Thus, the application of the Adaptive Fuzzy PI + Fuzzy PD controller is expected to be valuable. The contribution of this project is to bring this country for more advanced in satellite systems in future as well as for the international market.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Based on National Aeronautics and Space Administration (NASA), satellite is referred to as the moon, planet or machine that orbits a planet or a star. Therefore, satellite can be categorized into two types which are natural satellite and artificial satellite. Examples of natural satellite are earth and moon. This is because the Earth orbits the sun while the moon orbits the Earth. Artificial satellite is commonly defined as a machine that is launched into space and orbits the Earth atmosphere. Thousands of man-made satellites move in orbit with specific function which are mainly for television and radio broadcasting, communication such as internet and phone calls, weather forecasting, agricultural monitoring system, Global Positioning System (GPS) and many more.

Orbit is a gravitational curve path that functions as a track for satellite movement in space. Basically, every planet and satellite has their own orbit in order to prevent them from collision. The Earth atmosphere, artificial satellite will orbit at three different levels: Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and High Earth Orbit (HEO); see Figure 1.1. Hence, different satellite orbits Earth at different heights as well as speeds and paths which depend on the characteristics and functions of the artificial satellite (Riebeek & Simmon, 2009). Satellites positioned at LEO consist of communication, military and observation satellites where the distance from the earth's surface is between 180 km to 2000 km. As for MEO, the height of the satellite positioned here is at approximately 2000 km to 35780 km above earth. This orbit is also known as polar orbit. Satellites positioned at this orbit are weather, observation and spy satellite. Last but not least, HEO is the further orbit which is 35780 km and above from earth's surface. Satellite positions here are space observation and weather observation satellite.

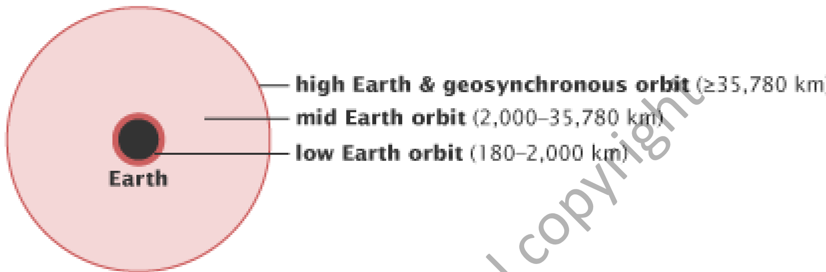

Figure 1.1: Earth satellite orbit (Riebeek & Simmon, 2009)

Generally, the Earth circles the sun in its orbit. Hence, the satellite design needs to move along with the Earth in order to fulfill its mission. This is achieved by hardware and software embedded in the satellite system. The system is required to continuously calibrate its instrumentation and optimize its control performance in the space for all time (Sidi, 2001). Advancement in technology has led to higher requirements on the performance of satellite control. Future satellite is expected to achieve highly accurate pointing position towards earth in the presence of large environmental disturbance.

1.2 Problem Statement

A satellite will orbit the Earth when its speed is balanced by the pull from the Earth's gravity. Without this balance, the satellite would fly in a straight line off into space or fall back to the Earth. Therefore, one of the most important problems in satellite design is the attitude stabilization and control. After the satellites were launched into the orbit by using a Poly-Pico-satellite Orbital Deployed (P-POD), the satellite will deploy in its altitude. However, the initial condition is unknown, where the satellite can be in a state of tumbling. The deployment sequence can cause the satellite to tumble at an undefined angular rate. At this time, the satellite needs to reduce the tumbling rate so that the satellite will be more stable and align to the normal orbit. Even though the satellite is stabilized after detumbling mode, there are factors that can influence its attitude when orbiting the Earth. The primary factors for a satellite are disturbances that could occur from gravitational forces of sun, moon, earth and also other planets in the solar system.

To handle these situations, there are some control techniques that can be used to reduce the satellite attitude control problems, such as artificial intelligent and adaptive control. In this research, Fuzzy controller is proposed to stabilize the satellite attitude since the controller can control a plant which does not have accurate models and lack of perfect knowledge. Due to time varying dynamic in the satellite environment an adaptation process is necessary to compensate the effect of unknown parameters variations in the satellite system. The important reasons why must the satellite oriented in its orbit with precise and specific direction are to maintain focused antenna and camera at certain point on Earth as well as keeping solar cells towards sun in most appropriate position for optimal storage of solar energy.