DEVELOPMENT OF SLIDING MODE CONTROL FOR ATTITUDE CONTROL OF SATELLITE

by

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LIST OF ABBREVIATIONS

ADCS	Attitude Determination Control System
ACS	Attitude Control System
ATSB	Astronautic Technology (M) Sdn Bhd
PID	Proportional Integral Derivative
SMC	Sliding Mode Control
SDBL	State Dependant Boundary Layer
CDBL	Constant-width Decaying Boundary Layer

LIST OF SYMBOLS

T	External torque
T_c	Control torque
T_d	Disturbance torque
s	Sliding variable
$f_2(s)$	Switching function
h_B	Angular momentum of rigid body
ω	Angular velocity
$\emptyset$	Roll (x-axis)
θ	Pitch (y-axis)
φ	Yaw (z-axis)
$U(t)$	Control input
σ	Sliding parameter
$\rho(x)$	Sliding variable
P	Identity matrix
$\in_0$	Upper boundary layer
$\in_1$	Lower boundary layer

Pembangunan Gelongsor Kawalan Mod untuk Kawalan Kedudukan Satelit

ABSTRAK

Kawalan kedudukan sistem satelit adalah kawasan penyelidikan yang menarik. Ini disebabkan oleh fleksibiliti dan kebolehgunaannya dalam pelbagai aplikasi. Dalam kerja ini, kami membangunkan sistem kawalan kedudukan dengan menggunakan data yang diperolehi dari RazakSAT, iaitu satelit mini Malaysia. Fokusnya ialah dengan menggunakan kawalan mod gelongsor kerana ia teguh terhadap ketidakpastian parameter dan gangguan luaran. Kajian ini mencadangkan penyesuaian dalam talian berkaitan dengan lebar lapisan sempadan berdasarkan norma kedudukan untuk sistem linear yang tidak menentu. Kami juga telah membangunkan lapisan sempadan yang sesuai dalam kawalan mod gelongsor untuk menghapuskan dan mengurangkan kesan getaran, jadi kaedah pergantungan lapisan sempadan kedudukan digunakan. Penggunaan kawalan mod adalah mengawal sikap untuk menangani dua isu utama iaitu mengurangkan getaran dan menghasilkan isyarat kawalan yang tepat. Sistem kawalan yang maju telah diuji untuk mengawal sikap satelit. Teknik lapisan sempadan kedudukan bergantung kepada pemboleh ubah keadaan sebagai komponen untuk menentukan lebar lapisan sempadan bergantung pada nilai keadaan semasa sebagai konsep utama. Reka bentuk sedemikian secara automatik menyesuaikan lebar lapisan sempadan berdasarkan keadaan sistem, dan akan lebih berupaya menangani situasi yang tidak dijangka. Prestasi sistem kawalan kami telah disahkan dengan membandingkan prestasinya dengan pengawal PID. Disamping itu, kaedah ini terbukti mampu mengendalikan gangguan dan dapat mengurangkan kesan getaran di dalam lapisan sempadan sambil mengekalkan keteguhan kawalan sikap satelit.

Development of Sliding Mode Control for Attitude Control of Satellite

ABSTRACT

Attitude control of a satellite system is an attractive research area. This is due to its versatility and applicability in a broad range of applications. In this paper, a new mathematical model is presented which provide more comprehensive mathematical representation of a model attitude control system by using characteristics data of RazakSAT. The focus of this project is on applying the sliding mode control (SMC) as it is robust against parameter of uncertainties and external disturbances. However, its control signal exhibits high frequency oscillations called chattering after the system state reaches the sliding surface. In order to reduce the chattering effect, the width of the boundary layer is adjusted based on the state norm for the uncertain linear system. Additionally, a suitable boundary layer in sliding mode control is also developed in order to eliminate and reduce the chattering effect. Hence, the state dependent boundary layer method has been proposed for attitude control to deal with two critical issues that is the chattering effect and control signal accuracy. The developed control system was tested for attitude control of satellite. The state dependent boundary layer technique will manipulated the state variables to determine the boundary layer width which depends on its current state value. Such a design will automatically adjusts the boundary layer width based on the system condition, and will be robust in dealing with unexpected situations. The performance of the control system was verified by comparing its performance with PID controller. Our experimental results the development control system is capable in handling the disturbance and reduce the chattering affect inside the boundary layer.

CHAPTER 1

INTRODUCTION

1.1 Research Background

In space, the attitude analysis of a satellite is constantly being computed within the system of the satellite. The attitude determination is the process of determining the orientation of the spacecraft relative position which is determined via sensors equipped. Meanwhile, attitude prediction is the process of forecasting the future orientation of the spacecraft using dynamical models, while attitude control is the process of orienting the spacecraft in a specified, predetermined direction. For the satellite's attitude to be able to be determined and controlled a subsystem called Attitude Determination and Control Subsystem (ADCS) is embedded in the satellite. The orientation in space with respect to different coordinate systems is referred to as the satellite attitude. ADCS are some of the most important subsystems of a satellite since the accuracy of its mission depends on this subsystem (Mbaocha, et al., 2016). Amongst several capacity subsystems, ADCS is an operation basic continuous installed framework and in that capacity gets extensive care to guarantee dependable operation in space (Wertz, 2002).

The satellite ADCS is generally formed of attitude sensors, actuators and flight-computer, which is use to execute the attitude control logic. Sensors such as infrared horizon sensor and dry turned gyros (DTG) are used to sense the satellite attitude and reaction and send the data to the flight-computer. Thus, attitude control will utilize this feedback for control calculation and accuracy then send direction to actuators (Hamzah, Yaacob, & Cherd, 2012). The state of mind movement of the satellite can be characterized as an arrangement of differential conditions. Movement is given by the position of the satellite body with various casing movement. The handy development outlines relying upon the satellite zone of utilization. Surrounded by a satellite mission, the nature of Attitude Control System (ACS) is a fundamental component for fulfilling extraordinary working situation. On behalf of ACS achievement is necessary to figure an appropriate mathematical model that agrees both combination of the control system and the simulation (Chelaru, Barbu, & Chelaru, 2011). The satellite considered in the simulation is a mini-satellite of Malaysia, RazakSAT by using the data from RazakSAT satellite project. This includes learning the basics of how a satellite operates in space. For example satellite orbits, environmental factors, coordinate systems, limits of the actuator system and avoid singularities with the use of quaternions. All of this can be both interesting and challenging with a background from earth based control systems.

Common satellites have three degrees of freedom (3DOF) system which is determined by ADCS. It is because the satellite needs specific observation from Earth's surface, an attitude controller is absolutely necessary (Alvenes, 2012). This research starts by choosing suitable techniques that might be forced and to get scientific demonstrating or modelling nonlinear proper satellite attitude reflected in the dynamic equations of motion and kinematic equations of motion. There are a few strategies that can be used to decide the control. For spacecraft, sliding mode control (SMC) is generally used as a part of control framework strategy because the features of SMC such as disturbance rejection; uncertainty is not sensitive, robust and fast response. Chattering is the utmost outcome as a drawback in SMC. Integrate boundless switching such that could move the framework from direction indicates towards the stable sliding surface is the factor which contributes to this actually undesirable phenomenon. Chattering result creates noise and high moving mechanicals part that can expand the monetary cost to replace the wear parts particularly in industry segment (Utkin & Lee 2006).

There are many modification have been done to overcome the effect of the chattering, for example, utilizing limit layer around the sliding mode surface. This is the one of the common chattering reduction methods that will change over all the chattering effect inside the boundary layer to sliding surface. The chattering result totally will be reduce or eliminate, but it also reduces the performance of the system and also the system robustness of the compensated system (Min-Shin Chen, Yean-Ren Hwang, 2002). Then, to overcome this disadvantages, the thought to utilize the boundary layer thickness in several functions as one of the arrangements is presented.

Finally, in this project that founded on this indication, state-dependant boundary layer (SDBL) method is recommended to enhance the ADCS performances. Since state variables can control the boundary layer width in command to reduce the chattering effect although keeping the robustness of the structure. The theory is suggested since the state variables moving from direction indicate the origin. It implies that the estimation of the state variable will likewise be decreased. This state space’s value can be used as an attendant to explain the width of the boundary layer when the state variables engaged whichever inside or outside the boundary layer region.

1.2 Problem Statement

The main challenge of the project is to model the behavior of RazakSAT's body dynamics and its actuator. RazakSAT have a non-linearity behavior and mathematical model often derive using linear time invariant system to reduce its complexity. Hence, the derived mathematical model is always just an approximation of the RazakSAT. However, the presence of potential unmodeled parameter might create stability to RazakSAT due to linearized model. Besides that, dynamics of RazakSAT is a fixed control model unable to accurately depict the dynamics of RazakSAT at all the time; this will affect the robustness of attitude control system. The sliding mode controller (SMC) is designed to effectively account for parameter uncertainty and the presence of unmodeled dynamics. For the sliding surface to be attractive, a switching function must be used in the control law, which causes chattering of the control signals. In order to reduce chattering, one can introduce a boundary layer around the sliding surface. There are other various approaches proposed to alleviate the chattering problem but the state dependant boundary layer is the simplest and widely used.

1.3 Research Objectives

This research project is primarily conducted to grasp the understanding of the sliding mode control for satellite. The main objective of this research comprises of the following tasks.

a) To derive the attitude dynamic model of RazakSAT satellite.

b) To develop the model for the RazakSAT attitude control system by using sliding mode control method.

c) To apply the state boundary layer in the control system to reduce the chattering effect.

d) To validate the simulated result to ensure the viability of the control method.

1.4 Scope of the Research

This project will focus on several scopes to achieve the objective.

a) Derivation of mathematical model for attitude control for satellite using the characteristic data of RazakSAT.

b) Apply the SMC control algorithm to the satellite's control system so as to eliminates chattering effect while maintain the robustness and stability of the system.

c) Research and investigation previous methods implemented in a satellite's control system in order to gain the ideas and concepts of eliminate and minimize the chattering effect; stability and robustness of a satellite system.

d) The simulation using MATLAB will be utilized to validate the proposed control method performance.

1.5 Organisation of Thesis

This research explores the topic to development of sliding mode control for attitude control of satellite. The research work carried out is presented in five chapters in this research.

Chapter 1 introduces the research background of attitude control of satellite. The problem statement and research objectives are included in this chapter. This chapter also gives an overview on how this dissertation is organized.

The literature survey on the satellite control, conventional methods used to determine the sliding mode control, and also the motivation towards this research work are presented in Chapter 2. The flow processes to achieve each objective are explained. The previous works on sliding mode control with satellite/spacecraft are surveyed and discussed.

Chapter 3 is devoted to the design methods and simulation methodologies. The design method involved in the derivation of mathematical model of satellite. This chapter describes the research methodology, the design arrangement, the derivation and the simulation methods.

The sliding mode control and chattering elimination technique that are developed in this research are presented in Chapter 4.

Chapter 4 discusses the state dependent boundary layer method used to eliminate the chattering effect inside SMC. Further, the comparison between the state dependent boundary layer methods and reasons to choose the best method is discussed. This chapter also describes the sliding mode control and satellite control system, simulated through the MATLAB Simulink. Further, the validation result for PID test also is presented in this chapter.

Chapter 5 summarizes all the findings along with the contributions made in this research work. This chapter also highlights the objectives met in this research as well as concludes the research and provides view for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a brief understanding on the methods and technique that have been proposed in order to achieve the intended objectives. The literature survey done in this chapter will be covered on the subjects of interest such as the importance of the sliding mode control to satellite itself, the conventional method used to determine the mathematical modeling of satellite control, the motivation towards the use Sliding Mode Control (SMC) and the choice of using state dependent boundary layer methods based on attitude control of satellite.

2.2 Attitude Dynamic and Kinematics

The distinction between kinematic and dynamics is that kinematics cover those aspects of motion that can be analyzed without consideration of forces and torques. when forces and torques are introduced, so that the motion are in the realm of dynamics (F. Landis Markley, 2014b). Attitude analysis is divided into determination, prediction and control (Wertz, 2002). Attitude systems include the sensors, actuators, avionics, algorithms, software, and ground support equipment used to determine and control the attitude of a vehicle. Attitude systems can have a variety of names, such as attitude determination and control system (ADCS) (Scott & John, 2008).

Attitude just means how a question is rotated or situated regard to a reference frame, and it is clear that the ideas of attitude control and rotation framework are profoundly interconnected. With which parameters one wish to define a question's state of mind is the thing that we mean by attitude control. Euler angles are a conventional and intuitive way of expressing the attitude (Li, et al,. 2017). The equation of motion of the attitude dynamics can be separated into two sets, the kinematic equations of motion and the dynamic equations of motion. Kinematics is the study of motion regardless of the powers that achieve the movement. The kinematic equations of motion are an arrangement of first-request differential conditions indicating the time advancement of the state of mind parameters. Upcoming spacecraft such as the Orbital Maneuvering Vehicle or “Remover” which attempts to seizure and eliminate huge space wreckages substances in orbit must to be capable to implement large angle and involved area maneuvers in space (Hui, Junfeng, & Baoyin, 2006).

Spacecraft attitude control is essential to meet mission pointing requirements, such as required sciences modes and thruster pointing requirement for orbital maneuvers (F. Landis Markley, 2014a). Mathematical model is put in nonlinear and linear form. The linear form is used for attitude control system synthesis. The attitude control system obtained is used in nonlinear form in order to maintain desired attitude. A few numerical simulations are made for standard input and the satellite behavior is obtained. The satellite model presented will be six DOF and used Cartesian coordinates (Teodor-Viorel Chelaru & Cristian Barbu, 2011). The equation of motion of a rigid body that performs attitude and translational motion (six degrees of freedom motion) is a nonlinear equation. Figure 2.1

shows the definition of the uses frames where the frame origin of reference frame is in the mass center of satellite and moves with it.

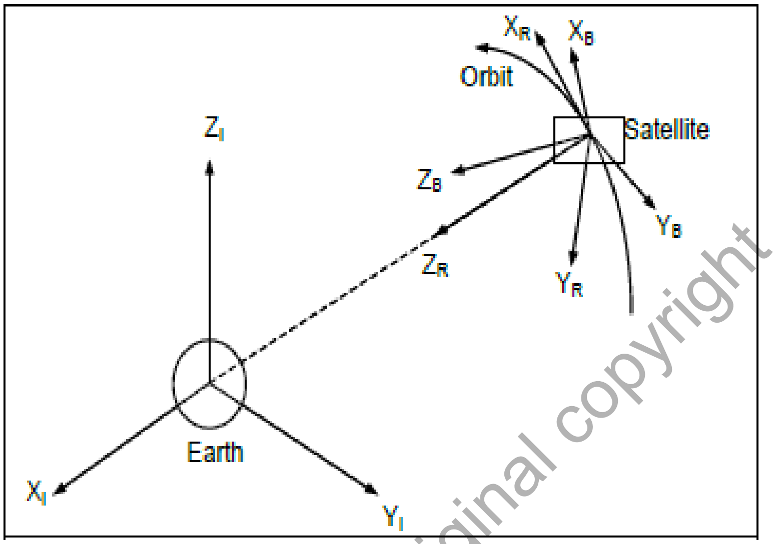

Figure 2.1 : Satellite will stabilized related to three axes

2.3 Sliding Mode Control

Sliding mode control is a nonlinear input control method which gives great robustness against demonstrating instabilities and outer unsettling influences. Be that as it may, as the exposure or disturbance rise, superior control information is required, and the control input may bring about an undesirable chattering phenomenon (Souvik & Mohamad, 2017; Fuh, 2008). The basic idea of sliding mode control is that; the desired system dynamics is first defined on a sliding mode surface in the state-space and a controller is then designed

An alternative approach in the control regulation of uncertain systems is the Sliding Mode Control (SMC) technique and its associated feedback control law of Variable Structure Control (VSC) systems. The outstanding feature of VSC is the excellent robustness and invariance properties in the face of disturbances and unmodeled dynamics. SMC is a high-speed discontinuous control which switches on a manifold; i. e. the gain switches between two values (structures) according to a rule that depends on the value of the state at each time instant. The objective of the switching control law is to drive the state trajectories of the nonlinear plant towards a prescribed switching (sliding) surface in the state space, and constrain them to lie upon this surface for all subsequent time. The motion that ideally arises when the system state crosses and re-crosses a switching surface is called sliding motion (Utkin & Lee, 2006). In the sliding mode the system is totally invariant to a class of matched disturbances and parameter variations with known bounds; thus, the closed-loop system dynamics are wholly characterized by the reduced order dynamics of the selected surface. Therefore, a crucial phase of SMC is to define a sliding surface so that the plant, restricted to the surface, has desired dynamics and properties such as stability to the origin, regulation and tracking (Liu, Guan, & Liu, 2006).

SMC design is carried out in two phases. The first step is to choose a sliding surface so that the plant state restricted to the surface has desired dynamics. The second step is to design a switched control that will drive the plant state to the switching surface and maintain it on the surface thereafter. Usually, a Lyapunov approach is used to achieve this second design phase (Rui Zhang et al., 2017). The Lyapunov function, which characterizes the motion of the state to the surface, is defined in terms of the surface. For each switched control structure one chooses the control law so that the derivative of this Lyapunov function is negative definite, thus guaranteeing motion of the state trajectory to the surface (Richard & Robert, 2011). A few modification of the boundary layer technique must be made to overcome these effects such as using different switching functions in control law, the effect can be seen as in the Figure 2.2. The sliding surface is moved repetitively toward the target sliding surface in order to ensure that the system trajectory is close to the actual surface during the whole control process (Husek, 2018).

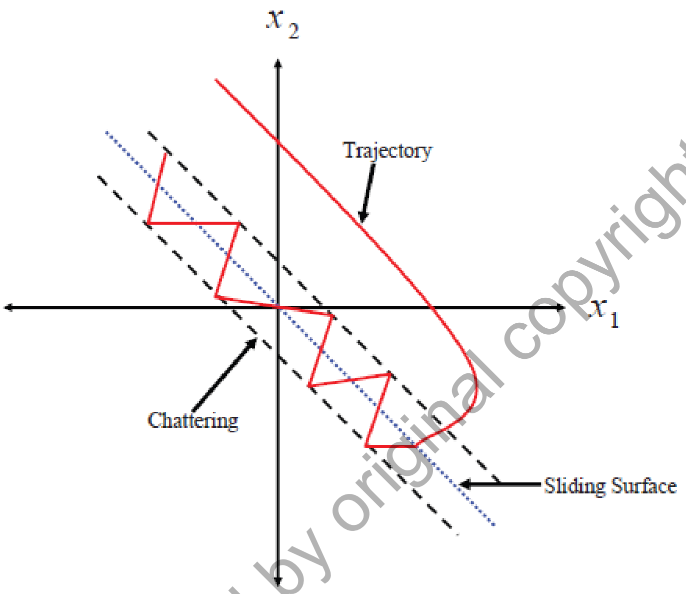

Figure 2.2 : Chattering effect inside the sliding surface

2.4 Motivation toward Satellite

Attitude is the three-dimensional orientation of a vehicle with respect to a specified reference frame. Attitude Control means placing the satellite in a specific predetermined direction. This consists of attitude stabilization and control maneuver. The satellite is assumed to be a rigid body operating in frictionless space with the disturbances (Mbaocha et al., 2016). The widespread use of Sliding Mode Control (SMC) in the spacecraft field has mostly covered the mechanical and dynamic properties of the satellite. SMC is one of the most important approaches to design robust nonlinear controllers for both linear and nonlinear system with parameter uncertainties and bounded input disturbances (Zihong, 2005). A SMC technique was first proposed by Russian control scientist, Emilyanov, in late 1950s. To implement the control scheme, a low-level SMC based on nonlinear dynamics is provided (Hui et al., 2006). Using a Lyapunov-based control design and stability analysis technique, we prove that the closed-loop system is globally asymptotically stable. The control law introduces a state-dependent layer around the sliding mode plane to remove chattering. This layer combines two types of boundary layers: a constant layer and a sector-shaped layer. The states will always enter the state-dependent boundary layer and the choice of the sliding mode will be seen to determine the ultimate system performance (Errmann & Purgeon, 2006).

To reduce chattering in sliding-mode control, a boundary layer around the switching surface is used, and a continuous control is applied within the boundary. The effects of various control laws within the boundary layer on chattering and error convergence in different systems are studied. New functions for chattering reduction and error convergence inside the boundary layer are proposed which are discontinuous in magnitude but not in