UNIVERSITI PUTRA MALAYSIA

IMPROVING SLIDING MODE CONTROL BY USING MODEL PREDICTIVE, FUZZY LOGIC, AND INTEGRAL AUGMENTED TECHNIQUES FOR AERIAL VEHICLE MODEL

AMIRHOSSEIN ZAERI

IMPROVING SLIDING MODE CONTROL BY USING MODEL PREDICTIVE, FUZZY LOGIC, AND INTEGRAL AUGMENTED TECHNIQUES FOR AERIAL VEHICLE MODEL

By

AMIRHOSSEIN ZAERI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2011

DEDICATION

This thesis is dedicated to

Prophet Mohammad

and

who follow him.

Abstract of thesis presented to the Senate of University Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

IMPROVING SLIDING MODE CONTROL BY USING MODEL PREDICTIVE, FUZZY LOGIC, AND INTEGRAL AUGMENTED TECHNIQUES FOR AERIAL VEHICLE MODEL

By

AMIRHOSSEIN ZAERI

November 2011

Chairman: Samsul Bahari Mohd Noor, PhD

Faculty: Engineering

Multi-input sliding mode control (SMC) is a robust controller that can be used to control linear and nonlinear plants to achieve desired performance in the presence of uncertainty and disturbance. Moreover, its stability is proven by Lyapunov's theorem.

In practical applications, SMC suffers from problems such as chattering, which increase the control effort that may lead to instability of the system. In addition, the SMC parameters ars off-line and can not be optimized. Improvement of SMC has been investigated by many researchers. One important suggested method, which can update some SMC parameters online, is model predictive sliding mode control (MPSMC) achieved by merging SMC and model predictive control (MPC). This approach is also confronted with some problems especially due to complicated

calculations and conservative strategy of nonlinear MPC for a nonlinear system at each sampling time.

This thesis relates to improvement of sliding mode controller performance by introducing a new strategy to merge SMC with linear MPC and fuzzy logic control (FLC). Boundary layer and integral augmented are also exploited.

Two different helicopter models are considered for testing under different controllers. The first is a two-degree-of-freedom (2-DOF) helicopter as a nonlinear high coupling 2-input 2-output laboratory experimental helicopter with motions in the pitch and yaw directions controlled by improved SMC controller. In this case, the results are compared with those of the PID controller based on the linear quadratic regulator algorithm (LQR-PID). The second one is a nonlinear quadrotor helicopter model as a four-rotor six-degree-of-freedom (6-DOF) helicopter which is a kind of autonomous unmanned aerial vehicle (UAV) system. The results of improved SMC are compared with those of an integral predictive nonlinear H_∞ control for this system. Moreover, a cart moving on a plane is considered for comparing the new suggested controller with model predictive integral sliding mode control.

The results reveal that the new merge of SMC with boundary layer (ISMC-BL), MPC, and FLC is an improved method for input tracking, optimization, and disturbance rejection performance for various applications namely the 2-DOF helicopter, the 6-DOF quadrotor helicopter, and the cart moving on a plane.

The main outcome of this research is the introduction of a new robust, stable, optimal, and intelligent control scheme which is a multi-input model predictive fuzzy integral sliding mode control with boundary layer (MPFISMC-BL). In this approach, a linear MPC, which considers constraints and cost function for optimal control performance at each sampling time, is used to design switching gains of control law. Moreover, equivalent control of MPFISMC-BL deals with nonlinearity of the system. Besides, FLC is used to calculate the slope of sliding surface as an intelligent tool based on fuzzy rules.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENAMBAH-BAIKAN ALAT KAWALAN CARA GELONGSOR DENGAN MENGGUNAKAN PENGANGGARAN MODEL, LOGIK SAMAR DAN LUASAN KAMIRAN TEKNIK UNTUK MODEL KENDERAAN AERIAL

Oleh

AMIRHOSSEIN ZAERI

November 2011

Pengerusi: Samsul Bahari Mohd Noor, PhD

Fakulti: Kejuruteraan

Alat kawalan cara gelongsor beberapa input atau "multi-input sliding mode controller (SMC)" adalah alat kawalan tegar yang boleh digunakan untuk mengawal mesin yang lelurus dan tidak lelurus untuk mencapai prestasi yang dikehendaki di bawah kehadiran ketidakpastian dan gangguan. Tambaha pula, kestabilannya dibuktikan oleh teori Lyapunov.

Di dalam aplikasi praktikal, SMC menghadapi masalah disebabkan oleh penggelatukan atau "chattering", yang menyebabkan pertambahan daya usaha lalu menjurus kepada ketidakstabilan sistem. Tambahan pula, pembolehubah SMC adalah di luar talian dan tidak boleh dioptimumkan. Penambah-baikan SMC telah dikaji oleh banyak penyelidik. Salah satu teknik penting yang dicadangkan ialah alat kawalan secara gelongsor penganggaran model atau "model predictive sliding mode control (MPSMC)" yang mana teknik ini boleh mengemaskini beberapa pembolehubah SMC secara di dalam talian. Teknik ini diperolehi dengan

meggabungkan SMC dan alat kawalan penganggaran model (MPC). Pendekatan ini juga mengalami beberapa masalah terutamanya berkenaan pengiraan yang rumit dan strategi yang kuno bagi MPC tidak lelurus untuk sistem yang tidak lelurus pada setiap masa pensempelan.

Tesis ini menyelidiki tentang memperbaiki prestasi alat kawalan lelurus dengan memperkenalkan strategi yang baru iaitu menggabungkan SMC bersama MPC lelurus dan juga alat kawalan samara atau “fuzzy logic control (FLC)”. Lapisan sempadan dan luasan kamiran juga digunakan.

Dua model helicopter yang berlainan diambil-kira untuk diuji di bawah alat kawalan yang berlainan. Yang pertama ialah helicopter makmal dua-darjah-kebebasan atau “two-degree-of-freedom (2-dof)” sebagai 2-input 2-output gandingan tinggi tidak lelurus yang mana pergerakannya pada sudut pic dan rewang dikawal oleh SMC yang telah ditambah-baik. Dalam kes ini, keputusannya telah dibandingkan dengan alat kawalan PID berdasarkan algoritme “linear quadratic regulator” (LQR-PID). Yang kedua ialah model helicopter empat-rotor tidak lelurus yang mempunyai 6-darjah-kebebasan jenis sistem “autonomous unmanned aerial vehicle (UAV)”. Keputusan SMV yang telah ditambah-baik telah dibandingkan dengan “integral predictive nonlinear H_∞” untuk sistem ini. Tambahan pula, pedati yang bergerak di atas kapal terbang ini diambil kira sebagai memperbandingkan alat kawalan yang dicadangkan dengan alat kawalan cara gelongsor kamiran penganggaran model.

Keputusan menunjukkan penggabungan terbaru SMC dan lapisan sempadan (ISMC-BL), MPC dan FLC adalah teknik yang lebih baik untuk penjejakan input, pengoptimuman dan prestasi dalam mengelakkan gangguan untuk pelbagai aplikasi seperti helicopter 2-darjah-kebebasan, 4-rotor-helicopter dengan 6-darjah-kebebasan dan pedati bergerak di atas kapal terbang.

Sumbangan utama yang diperolehi dari penyelidikan ini ialah memperkenalkan skim kawalan yang baru lagi tegar, stabil, optimal, dan bijak iaitu alat kawalan beberapa-input penganggaran model kamiran samar cara gelongsor dengan lapisan sempadan atau “multi-input model predictive fuzzy integral sliding mode control with boundary layer (MPFISMC-BL)”. Dalam pendekatan ini, MPC lelurus, yang mengambil kira kekangan dan fungsi kos untuk setiap masa pensempelan untuk mencapai keputusan kawalan yang optimum, digunakan untuk mereka keuntungan pensuisan undang-undang kawalan. Tambahan pula, kawalan yang sama MPFISMC-BL berkait dengan sistem tidak lelurus. Tambahan pula, FLC digunakan untuk mengira kecerunan permukaan gelongsor sebagai alat kebijaksanaan berdasarkan undang-undang samar.

ACKNOWLEDGEMENTS

In Quran, surat 27, ayat 40, it is said “This is by the grace of my Lord that he may test me whether I am grateful or I am thankless”. Then, my main appreciation is to Allah that kindly helps me every time and everywhere.

I would like to thank my compassionate supervisor, Dr. Samsul Bahari Mohd Noor, for his overall support, guidance, and patience all these years. I am grateful to my supervisory committee members, Dr. Maryam Mohd Isa and Dr. Farah Saleena Taip and my examiner committee members, Dr. Mohd Hamiruce Marhaban, Dr. Renuganth Varatharajoo, Prof. Dr. Sarah Spurgeon, and Dr. Thomas Choong Shean Yaw for their advices and insightful comments which guide me through the proper direction.

I would like to express my deepest gratitude to my beloved wife, Aida Esmaeilian, for her endless support during ten years living beside her. I also wish to thank my beloved sister, and brothers for their unconditional support and love. I would like to dedicate this thesis to the memory of my mother, Fatemeh, for her concern and her pray for me during her life, and the memory of my father, Abbas. I wish Allah grant them eternal rest. I also dedicate this thesis to my darling son, Mohammad Hossein, who has already stepped into this marvelous world.

I would also like to thank all who helped me in the research work. I am grateful to Dhideen Mohammed Salih, Hasma Mansor, Ali Rafiei, Ehsan Keramati, Omar Farogh, and Hazem Ali for their help during my research.

I certify that an Examination Committee has met on **17 November 2011** to conduct the final examination of Amirhossein Zaeri on his Doctor of Philosophy thesis entitled "Improving Sliding Mode Control by Using Model Predictive, Fuzzy Logic, and Integral Augmented Techniques for Aerial Vehicle Model" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Examination Committee were as follows:

Thomas Choong Shean Yaw, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Hamiruce Marhaban, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Renuganth Varatharajoo, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Sarah Spurgeon, PhD
Professor
Faculty of Engineering
University of Kent
United Kingdom
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Samsul Bahari Mohd Noor, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Maryam Mohd Isa, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Farah Saleena Taip, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

AMIRHOSSEIN ZAERI

Date: 17 November 2011

TABLE OF CONTENTS