UNIVERSITI PUTRA MALAYSIA

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

AMIRHOSSEIN ZAERI

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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

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November 2011

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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 are 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 $H_{\infty}$ 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 KENDERAAAN AERIAL

Oleh

AMIRHOSSEIN ZAERI

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Pengerusi: Samsul Bahari Mohd Noor, PhD

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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. Tambahan 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.


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.
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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.

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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
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