UNIVERSITI PUTRA MALAYSIA

METHODOLOGY OF FUZZY-BASED TUNING FOR SLIDING MODE CONTROLLER

FARZIN PILTAN

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By

FARZIN PILTAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

I dedicate this dissertation to:

My wife, **Nazi** for all lovely support in these years,

My dearest daughter **Pantea** who is the aim of my life,

My **Mother**; My Moon

and

My **Father**; My Sun

Abstract of thesis to be presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

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Chairman: Nasri. B. Sulaiman, PhD

Faculty: Engineering

Design a nonlinear controller for second order nonlinear uncertain dynamical systems is one of the most important challenging works. This thesis focuses on the design, implementation and analysis of a chattering free Mamdani's fuzzy-based tuning error-based fuzzy sliding mode controller for highly nonlinear dynamic PUMA robot manipulator, in presence of uncertainties. In order to provide high performance nonlinear methodology, sliding mode controller is selected. Pure sliding mode controller can be used to control of partly known nonlinear dynamic parameters of robot manipulator. Conversely, pure sliding mode controller is used in many applications; it has two important drawbacks namely; chattering phenomenon which it can causes some problems such as saturation and heat the mechanical parts of robot manipulators or drivers and nonlinear equivalent dynamic formulation in uncertain dynamic parameter.

In order to reduce the chattering this research is used the linear saturation function boundary layer method instead of switching function method in pure sliding mode controller and fuzzy sliding mode controller. In order to solve the uncertain nonlinear dynamic parameters, implement

easily and avoid mathematical model base controller, Mamdani's performance/error-based fuzzy logic methodology with two inputs and one output and 49 rules is applied to pure sliding mode controller. The results demonstrate that the error-based fuzzy sliding mode controller with saturation function is a model-free controllers which works well in certain and partly uncertain system. Pure sliding mode controller with saturation function and error-based fuzzy sliding mode controller with saturation function have difficulty in handling unstructured model uncertainties. To solve this problem applied fuzzy-based tuning method to error-based fuzzy sliding mode controller for adjusting the sliding surface gain (λ). Since the sliding surface gain (λ) is adjusted by fuzzy-based tuning method, it is nonlinear and continuous. In this research new λ is obtained by the previous λ multiple sliding surface slopes updating factor (α) which is a coefficient varies between half to one. Fuzzy-based tuning error-based fuzzy sliding mode controller is stable model-free controller which eliminates the chattering phenomenon without to use the boundary layer saturation function. Lyapunov stability is proved in fuzzy-based tuning fuzzy sliding mode controller based on switching (sign) function. This controller has acceptable performance in presence of uncertainty (e.g., overshoot=0%, rise time=0.8 second, steady state error = 1e-9 and RMS error=1.8e-12). Fuzzy-based tuning error-based fuzzy sliding mode controller and Guo and Woo adaptive fuzzy sliding mode controller have been comparatively evaluated through simulation, for robotic manipulator. Most of nonlinear controllers need real time mobility operation so one of the most important devices which can be used to solve this challenge is Field Programmable Gate Array (FPGA). FPGA can be used to design a controller in a single chip Integrated Circuit (IC). To have higher implementation speed with good performance SMC is implemented on Spartan 3E FPGA using Xilinx software (controller computation time=30.2 ns, Max frequency=63.7 MHz and controller action frequency=33 MHZ).

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

KAEDAH PENALAAN SAMAR-BERASASKAN UNTUK PENGAWAL MOD GELANGSAR

Oleh

FARZIN PILTAN

November 2011

Pengerusi: Nasri. B. Sulaiman, PhD

Fakulti: Kejuruteraan

Merekabentuk pengawal tak linear untuk sistem dinamik tertib kedua yang tidak menentu merupakan salah satu daripada kerja-kerja terpenting yang mencabar. Tesis ini memberi tumpuan kepada rekabentuk, pelaksanaan dan analisis kabur-penalaan berasaskan gelugutan percuma Mamdani berasaskan kesilapan kabur pengawal mod gelangsar bagi pengolah dinamik robot PUMA yang sangat tak linear, dengan kehadiran ketidaktentuan. Pengawal mod gelangsar yang tulen boleh digunakan untuk mengawal sebahagian parameter dinamik tak linear yang diketahui untuk pengolah robot. Dalam usaha untuk mengurangkan gelugutan, kajian ini menggunakan kaedah lapisan sempadan ketepuan fungsi linear bukan fungsi menukar kaedah pengawal mod tulen gelongsor dan pengawal mod gelangsar kabur. Untuk menyelesaikan parameter-parameter dinamik tak linear yang tidak menentu, melaksanakan dengan mudah dan mengelakkan model pengawal asas matematik, prestasi Mamdani / kesilapan berasaskan kaedah logik kabur dengan dua masukan dan satu keluaran dan 49 peraturan digunakan kepada pengawal mod gelangsar

tulen. Keputusan menunjukkan bahawa mod berasaskan kesilapan pengawal gelongsor kabur dengan fungsi tepu adalah pengawal model bebas yang berfungsi dengan baik dalam sistem tertentu dan sebahagiannya tidak menentu. Untuk menyelesaikan masalah ini kaedah penalaan kabur berasaskan kepada kesilapan kabur pengawal mod gelangsar dengan penyesuaian gandaan permukaan gelangsar (λ) digunakan. Oleh kerana gandaan permukaan gelangsar (λ) diselaraskan oleh kaedah penalaan berasaskan kabur, ianya tak linear dan berterusan. Dalam penyelidikan ini nilai baru λ diperolehi oleh nilai λ sebelumnya yang mempunyai berbilang cerun permukaan gelangsar yang mengemas kini faktor (α) iaitu satu pekali yang berubah di antara setengah hingga satu. Berdasarkan kepada penalaan kesilapan-kabur pengawal mod gelangsar yang merupakan pengawal bebas model yang stabil yang menghapuskan fenomena gelugutan tanpa menggunakan fungsi lapisan sempadan tepu. Kestabilan Lyapunov dibuktikan dalam penalaan kabur berasaskan pengawal mod gelangsar kabur berdasarkan pensuisan (tanda) fungsi. Pengawal ini mempunyai prestasi yang boleh diterima dengan kehadiran keadaan yang tidak menentu (contohnya, terlajak = 0%, masa naik = 0.8 saat, ralat keadaan mantap = 1E-9 dan ralat RMS = 1.8e-12). Kebanyakan pengawal tak linear memerlukan masa operasi mobiliti sebenar jadi salah satu peranti yang paling penting yang boleh digunakan untuk menyelesaikan cabaran ini adalah tatasusunan get boleh aturcara medan (FPGA). FPGA boleh digunakan untuk merekabentuk satu pengawal dalam satu cip tunggal litar bersepadu (IC). Untuk mempunyai kelajuan yang yang lebih tinggi dalam pelaksanaan dengan prestasi SMC yang baik dilaksanakan pada Spartan 3E FPGA menggunakan perisian Xilinx (masa pengiraan pengawal = 30.2 ns, frekuensi maximum = 63,7 MHz dan pengawal tindakan kekerapan = 33 MHZ).

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of **Master of Science.** The members of the Supervisory Committee are as follows:

Nasri b. sulaiman, PhD

Lecturer

Faculty of Engineering

Universiti Putra Malaysia

(Chairman)

Mohammad Hamiruce b. Marhaban, Assoc. Prof. Dr

Lecturer

Faculty of Engineering

Universiti Putra Malaysia

(Member)

Abdul Rahman b. Ramli, Assoc. Prof. Dr

Lecturer

Faculty of Engineering

Universiti Putra Malaysia

(Member)

HASANAH MOHD GHAZALI, 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 it has not been previously, and is not concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

FARZIN PILTAN

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