UNIVERSITI PUTRA MALAYSIA

TRADITIONAL AND HIGHER ORDER SLIDING MODE CONTROL OFMEMS OPTICAL SWITCH

EHSAN KERAMATI

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By

EHSAN KERAMATI

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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To

Whom I am following

Abstract of thesis presented to the senate of University Putra Malaysia in fulfilment of the requirement of the degree of Master of Science

TRADITIONAL AND HIGHER ORDER SLIDING MODE CONTROL OF MEMS OPTICAL SWITCH

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October 2010

Chairman: Samsul Bahari Mohd Noor , PhD

Faculty: Engineering

MEMS optical switches are the switches in which microelectromechanical systems technique is used to fabricate tiny mirrors in order to reflect the light beams directly from one fiber optic to another.

This thesis mainly focused on closed-loop control of MEMS optical switch. The purpose of the control system is that to control the position of the micro-mirror. It is important to note that the relation between applied voltage and position in the electro-static actuators is nonlinear. In addition to this inherently nonlinear nature,

the accurate mathematical model of the system is hard to derive. Therefore, it is so crucial to choose a control approach that handles uncertainties and nonlinearities.

Based on the above discussions, to control the position of the micro-mirrors the most appropriate approach is the so-called sliding mode control scheme which is the robust nonlinear method. Both traditional sliding mode (TSM) and higher order sliding mode (HOSM) algorithms have been applied to the system. In order to investigate the robustness of the proposed controllers, external disturbance and parametric uncertainty are exerted to the system. In HOSM control system, robust exact differentiator is used to estimate the time derivatives of the sliding variable. Tuning the parameters of the controllers is carried out by using particle swarm optimization (PSO) method instead of conventional try and error.

Apart from the entire above mentioned discussions, TSM control scheme has a drawback called 'chattering'. It is a harmful phenomenon caused either by switching imperfections or unmodelled dynamics of the system and limits the application of the TSM method in reality. Among all the methods that have been proposed to avoid chattering, HOSM algorithm is used in this work to eliminate this disadvantage.

The results of the TSM method show that the controller stabilizes the output at the different desired reference signals. Time response of the system shows faster system rather than previous TSM control system, the settling time decreased from 2.4 *(s)* to 0.0019 *(s)*. Moreover, the proposed TSM controller introduces smoother output compare to previous work. In term of robustness, the controller is robust against the

uncertainties and disturbances. However, the main drawback of the TSM method, chattering, is clearly appeared in the control signal.

On the other hand, implementing HOSM controller eliminated the mentioned drawback while it keeps the advantages of TSM method. Apart from chattering elimination, it should be noted that the HOSM controller improved the accuracy of the output compared to TSM control system; magnitude of the steady state error has been decreased from 3.54×10^{-8} *(m)* to 4.34×10^{-10} *(m)*.

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

KAWALAN MOD GELANGSAR TRADISI DAN TERTIB TINGGI BAGI SUIS OPTIK MEMS

OLEH

EHSAN KERAMATI

Oktober 2010

Pengerusi : Samsul Bahari Mohd Noor, PhD

Fakulti : Kejuruteraan

Suis optik MEMS adalah sejenis suis yang mana teknik sistem mikroelektromekanikal digunakan untuk memperbuat cermin kecil untuk memantulkan alur cahaya secara terus dari satu gentian optik ke gentian optik yang lain.

Tesis ini memberi focus kepada kawalan litar tertutup suis optikal MEMS. Tujuan sistem kawalan ini ialah untuk mengawal kedudukan cermin mikro. Adalah penting untuk mengetahui hubungan di antara voltan dan kedudukan di dalam penggerak

elektro-statik adalah tidak linear. Tambahan pula, model matematik yang tepat sangat susah untuk diperolehi. Jadi, terdapat ketidakpastian di dalam model matematik seharusnya diambil kira di dalam prosedur rekaan, di samping faktor ketidaklinearan.

Berdasarkan perbincangan di atas, untuk mengawal kedudukan cermin mikro, pendekatan yang terbaik ialah dengan menggunakan satu teknik yang dipanggil "sliding mode" yang mana ia mempunyai cirri-ciri kekuatan dan ketegapan yang tidak linear. Kedua-dua algoritma yang dipanggil "traditional sliding mode (TSM)" dan "higher order sliding mode (HOSM)" telah diaplikasikan kepada sistem ini. Untuk menyelidiki tahap kekuatan dan ketegapan alat kawalan yang dicadangkan, gangguan luar dan ketidakpastian parametric diperkenalkan kepada sistem ini. Di dalam sistem kawalan HOSM, "robust exact differentiator" digunakan untuk menganggarkan masa perbezaan untuk pembolehubah "sliding". Untuk melaraskan parameter alat kawalan, teknik yang dipanggil "partical swarm optimization (PSO)"digunakan di dalam penyelidikan ini, bukan seperti kaedah cuba jaya yang biasanya digunakan sebelum ini.

Selain daripada perbincangan di atas, skim kawalan TSM mempunyai kelemahan yang dipanggil "chattering". Ia adalah fenomena yang berbahaya yang boleh menyebabkan masalah pertukaran atau dinamik yang tidak boleh dimodelkan di dalam sistem yang mana is boleh mengehadkan aplikasi TSM di alam realiti. Di antara semua kaedah yang dicadangkan untuk mengelakkan masalah "chattering", algoritma HOSM digunakan untuk mengatasi kelemahan ini.

Keputusan dari kaedah TSM menunjukkan alat kawalan menstabilkan output pada beberapa isyarat rujukan. Masa gerak balas bagi system yang dicadangkan ini lebih pantas berbanding system kawalan TSM yang sebelum ini, masa selesai didapati menurun dari 2.4 *(s)* kepada 0.0019 *(s)*. Tambahan pula, kawalan TSM yang dicadangkan memperkenalkan output yang lebih lancar berbanding hasil kerja-kerja penyelidikan terdahulu. Dari segi kekuatan dan ketegapan, alat kawalan ini lebih tegap menangani masalah ketidakpastian dan gangguan. Walaubagaimanapun, "chattering" jelas sekali muncul di dalam isyarat kawalan.

Di samping itu, mengaplikasikan alat kawalan HOSM dapat mengatasi kelemahan di atas namun ia mengekalkan kebaikan kaedah TSM. Selain mengatasi masalah "chattering", HOSM dapat memperbaiki ketepatan pada output berbanding sistem kawalan TSM; ralat tetap didapati menurun dari 3.54×10^{-8} *(m)* kepada 4.34×10^{-10} *(m)*.

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APPROVAL

I certify that an Examination Committee has met on **19 Oct 2010** to conduct the final examination of **Ehsan Keramati** on his **Master of Science** thesis entitled "**TRADITIONAL AND HIGHER ORDER SLIDING MODE CONTROL OF MEMS OPTICAL SWITCH**" in accordance with University Pertanian Malaysia (Higher Degree) Act 1980 and University Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree.

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

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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 University Putra Malaysia or other institutions.

EHSAN KERAMATI

Date: 19 Oct 2010

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