MODELING AND CONTROL OF PIEZOELECTRIC STACK ACTUATORS WITH HYSTERESIS

MARWAN NAFEA MINJAL

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical - Mechatronics & Automatic Control)

Faculty of Electrical Engineering
UniversitiTeknologi Malaysia

AUGUST 2013

ACKNOWLEDGEMENT

First and foremost, I am thankful to Allah S.W.T for everything, especially for his guidance in accomplishing this level of study.

I am grateful to my beloved parents and sister for their continuous support. Without their love and encouragement, I would never have succeeded in my study.

I wish to thank my supervisor Assoc. Prof. Dr. Zaharuddin bin Mohamed for his continuous support and supervisions. A lot of creative thoughts and valuable discussion have had significantly influence this final year project report. This project would not have been possible without the support and supervision from him.

Thanks to all my lecturers who taught me during my master study, the incorporation of the knowledge you gave is what brought all the pieces together.

Last but not least, thanks to my friends and classmates for all of their support during my study and their assistance during the research, especially Amirah ‘Aisha Badrul Hisham.

ABSTRACT

Piezoelectric actuators are popularly applied as actuators in high precision systems due to their small displacement resolution, fast response and simple construction. However, the hysteresis nonlinear behavior limits the dynamic modeling and tracking control of piezoelectric actuators. This thesis studies a dynamic model of a moving stage driven by piezoelectric stack actuator. The Bouc-Wen model is introduced and analyzed to express the nonlinear hysteresis term of the piezoelectric stack actuator, where the values of the parameters of the model have been taken from a previous work. The simulated results using MATLAB/Simulink demonstrate the existence of the hysteresis phenomenon between the input voltage and the output displacement of the piezoelectric stack actuator, and validate the correctness of the model. Moreover, a Luenberger observer is designed to estimate the hysteresis nonlinearity of the system, and then combined with the voltage input signal to form a Luenberger-based feedforward controller to control the displacement of the system. Furthermore, a Proportional-Integral-Derivative (PID) feedback controller is integrated with the feedforward controller to achieve more accurate output displacement, where the gains of the PID controller are optimized using Particle Swarm Optimization. Several performance index formulas have been studied to get the best solution of the PID's gains. An Integral Time Squared Error plus Absolute Error performance index formula has been proposed to achieve zero overshoot and steady-state error. The simulated results accomplished using MATLAB/Simulink show the ability of the designed controllers to vastly reduce the amount of error of the output displacement and the response time of the system.

ABSTRAK

Pemacu piezoelektrik popular digunakan sebagai pemacu system berketepatan tinggi memandangkan ia memberikan resolusi sesaran yang kecil, tindak balas yang cepat dan konstruksi yang mudah. Namun, sifat histerisis yang tidak linear menghadkan pemodelan dinamik dan penjejakan bagi pemacu ini. Tesis ini mengkaji model dinamik bagi pemacu bergerak berperingkat dipacu oleh aktuator piezoelektrik bertingkat. Model Bouc-Wen diperkenalkan dan dianalisis untuk menyatakan terma histerisis tidak linear bagi aktuator piezoelektrik bertingkat, di mana nilai parameter yang digunakan bagi model ini diambil daripada projek yang terdahulu. Keputusan simulasi dengan menggunakan MATLAB/Simulink menunjukkan tentang kewujudan fenomena histerisis antara voltan input dan sesaran output bagi pemacu piezoelektrik berlapis, dan mengesahkan kesahihan model. Tambahan pula, pemerhati Luenberger telah direka untuk menganggarkan histerisis tidak linear bagi sistem dan kemudian menggabungkan dengan isyarat input voltan membentuk satu pengawal suapbalik hadapan berasaskan Luenberger untuk mengawal sesaran sistem. Tambahan pula, satu pengawal suapbalik berasaskan Perkadaran-Pembezaan-Kamiran (PID) disepadukan dengan pengawal suapbalik hadapan untuk mencapai sesaran output yang lebih tepat, di mana peningkatan pengawal PID dioptimumkan menggunakan Particle Swarm Optimization. Beberapa indeks prestasi telah dikaji untuk mendapatkan penyelesaian yang terbaik untuk nilai gandaan PID. Formula gabungan indek kamiran ralat kuasa dua dan indeks ralat mutlak telah dicadangkan untuk mencapai lajakan sifar dan ralat keadaan mantap sifar. Keputusan-keputusan simulasi yang diperoleh dengan menggunakan MATLAB/Simulink menunjukkan keupayaan pengawal yang direka dengan mengurangkan jumlah ralat sesaran output yang besar dan mengurangkan masa tindak balas sistem.