UNIVERSITI PUTRA MALAYSIA

DESIGN OF LOW ORDER QUANTITATIVE FEEDBACK THEORY AND H-INFINITY -BASED CONTROLLERS USING PARTICLE SWARM OPTIMISATION FOR A PNEUMATIC ACTUATOR SYSTEM

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By

HAZEM I. ALI

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

October 2010

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DEDICATION

I dedicate this work

to

My dearest Mother and Father,

My Fiancée who has waiting for me for a long time,

My Sisters,

My Brothers,

and

My Friends

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

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October 2010

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Faculty : Engineering

The quantitative feedback theory (QFT) and H_∞ are the two most popular, well defined and powerful robust control techniques. These techniques are used to achieve high performance of the system in the presence of system uncertainties and disturbances.

This work is concerned with the design of simplified structure and low order robust control algorithms based on QFT and/or H_∞ techniques for pneumatic servo actuator system. The particle swarm optimization (PSO) method is used to tune the parameters of the controller and weighting functions subject to QFT and/or H_∞ constraints. These algorithms are designed to achieve the robustness over a wide range of system

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parameters change and disturbances. The pneumatic system parameters uncertainty is the main problem in the design of a desired control algorithm for this plant. Where the variation in thermodynamic conditions causes an uncertainty in a number of the model's parameters and the large change of pneumatic actuator load leads to variation in the actuator dynamics. Therefore, two ranges of pneumatic actuator load variation are considered. The first one is a small range variation when the load mass, M=0.1 to 5 kg which is widely required in many industrial applications of pneumatic actuators for control of machines such as robots. The second one is a wide range variation when the load mass M=0.1 to 100 kg which is required for the pneumatic servo actuators when they are used in missiles applications.

PSO based QFT control algorithm is proposed for pneumatic servo actuator system. The PSO algorithm is used to optimize the loop-shaping step (subject to QFT constraints), which is performed manually in the standard QFT control design. The obtained controller is simpler structure and lower order than the standard QFT controller and the same robustness of the standard QFT control is achieved. On the other hand, the design of conventional H_∞ control with structured and unstructured uncertainties is also presented. The PSO algorithm is used to minimize the infinity norm of the transfer function of the nominal closed loop system to obtain the optimal parameters of the weighting functions. This method simplifies the design procedure and leads to obtain a sub-optimal controller can achieve the position control of pneumatic actuator.

A method for robust controllers design using restricted structure controllers such as

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PID, Lag-Lead and deadbeat control algorithms is presented. The method uses particle swarm optimization (PSO) to tune the controller and performance weighting function parameters by minimizing a cost function subject to H_∞-norm specifications. It is shown that the designed controllers present robustness over a wide range of parameters change. Also, it can be shown that the proposed deadbeat control algorithm can achieve more desirable time and frequency responses specifications with simpler structure and lower order controller.

Since there is a lot of parallelism between QFT and H_∞ control techniques and they may complement one other, a robust hybrid H_∞/QFT controller is designed to assure robust stability and robust performance of the uncertain pneumatic servo actuator system. This controller achieves in the same time the design requirements that arise from both QFT and H_∞ control techniques. The PSO algorithm is used to obtain the controller parameters by minimizing a new proposed cost function subject to QFT and H_∞ constraints. The PSO based hybrid H_∞/QFT controller can give automatically better performance (in terms of rise time and settling time) than the previous works that used only one of them.

Finally, a comparison between all the designed controllers in this work shows that the superiority of the PSO based H_∞ deadbeat controller. It can achieve the same robustness of conventional methods with simple structure and low order controller and with more desirable time and frequency response specifications.

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

REKAAN ALAT KAWALAN TEGAR QUANTITATIVE FEEDBACK THEORY DAN H-INFINITY ATURAN RENDAH MENGGUNAKAN PARTICLE SWARM OPTIMISATION UNTUK SISTEM PERANTI PNEUMATIK

Oleh

HAZEM I. ALI

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Quantitative Feedback Theory (QFT) dan H_∞ adalah dua alat pengawal yang terkemuka, jelas dan kuat lagi tegap. Teknik ini biasanya digunakan untuk mencapai prestasi yang tinggi sewaktu kehadiran ketidakpastian dan gangguan di dalam sistem. Kedua-dua alat kawalan ini mempunyai ciri-ciri yang hampir sama dan saling melengkapi di antara satu sama lain.

Penyelidikan di dalam tesis ini merencana alat kawalan yang kuat lagi tegap dalam masa yang sama mempunyai struktur yang mudah dan aturan yang rendah dengan menggunakan algoritme QFT dan hinf. Particle Swarm Optimization (PSO) digunakan

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untuk melaraskan parameter dan fungsi pemberat di dalam QFT dan/atau Hinf. Algoritma ini direka untuk mencapai tahap kekuatan dan ketegapan untuk ketidakpastian dan gangguan dalam julat yang besar. Algoritm-algoritme ini telah diaplikasikan kepada aktuator udara dengan kuasa servo atau "pneumatic servo actuator" yang dikawal oleh injap paip jet bagi menunjukkan rencana prosedur untuk algoritme kawalan yang dicadangkan. Ketidakpastian parameter di dalam sistem pneumatic adalah masalah utama di dalam rekaan. Dua julat variasi beban di dalam actuator pneumatic diambil kira di dalam penyelidikan ini. Yang pertama, variasi yang kecil apabila berat beban M=0.1 hingga 5kg manakala yang kedua ialah mengambilkira variasi yang lebih besar iaitu M=0.1 hingga 100kg.

Algoritme PSO dan QFT alat kawalan direka dan diuji pada "pneumatic servo actuator". Algoritme PSO digunakan untuk membentuk lingkaran atau "loop shaping" secara automatik di dalam rekaan alat kawalan QFT. Hasilnya, alat kawalan yang diperolehi adalah mudah dan mengandungi aturan yang lebih rendah berbanding dengan alat kawalan QFT yang biasa, namun mempunyai tahap kekuatan dan ketegapan yang sama. Di samping itu, H_∞ konvensional yang berstruktur dan tidak berstruktur juga diketengahkan di dalam tesis ini. Algoritme PSO digunakan untuk meminimumkan "infinity norm" dalam fungsi pemindahan atau "transfer function" dalam sistem litar tertutup nominal untuk mendapatkan parameter fungsi pemberat terpilih yang optimal. Cara ini dapat meringkaskan prosedur dalam rekaan dan seterusnya mencapai alat pengawal yang kuat lagi tegap untuk mengawal posisi "pneumatic actuator".

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Walaubagaimanapun, dengan menggunakan kaedah ini, alat kawalan masih mengandungi aturan yang tinggi.

Satu kaedah untuk alat pengawal yang kuat dan tegap menggunakan algoritme struktur PID terbatas, Lag-Lead dan "deadbeat" kawalan juga diberi perhatian. Kaedah ini menggunakan PSO untuk melaras alat pengawal dan prestasi fungsi pemberat parameter dengan meminimumkan fungsi kos tertakluk kepada H_∞-norm spesifikasi. Hasil penyelidikan mendapati alat pengawal yang dicadangkan mempunyai kekuatan dan ketegapan pada julat parameter yang besar. Disamping itu, "deadbeat" yang dicadangkan boleh mencapai gerakbalas masa dan frekuensi yang dikehendaki.

Kombinasi di antara alat kawalan H_∞ dan QFT di renkbentuk untuk memastikan ketahanan prestasi dan kestabilan sistem "pneumatic servo actuator". Dengan menggunakan rekaan ini, kehendak rekaan kedua-dua teknik QFT dan H_∞ ini tercapai. Algoritme PSO digunakan untuk mendapatkan parameter alat kawalan dengan meminimumkan fungsi kos yang dicadangkan, mengambil kira QFT dan H_∞ "constraints". Akhir sekali, alat kawalan H_∞ dan QFT hibrid boleh memberikan prestasi yang lebih baik berbanding dengan hasil-hasil kerja yang sebelumnya yang mana hanya salah satu alat kawalan yang digunakan.

Akhir sekali, perbandingan di antara kesemua alat kawalan yang telah direncana dilakukan. Di akhir penyelidikan, hasil, menunjukkan alat kawalan PSO berdasarkan H_∞ deadbeat adalah yang terbaik. Ia dapat mencapai kekuatan dan ketegapan yang

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sama dengan teknik convensional tetapi dengan struktur yang lebih mudah, mempunyai aturan yang rendah dan gerak balas masa dan frekuensi yang lebih dikehendaki.

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I certify that a Thesis Examination Committee has met on 22/10/2010 to conduct the final examination of Hazem I. Ali on his thesis entitled "DESIGN OF LOW ORDER QUANTITATIVE FEEDBACK THEORY AND H-INFINITY-BASED CONTROLLERS USING PARTICLE SWARM OPTIMISATION FOR A PNEUMATIC ACTUATOR SYSTEM" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the University Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the Student be awarded the relevant Doctor of Philosophy.

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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:

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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.

HAZEM I. ALI

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