PREDICTIVE FUNCTIONAL CONTROL WITH REDUCED-ORDER OBSERVER DESIGN USING PARTICLE SWARM OPTIMIZATION FOR PNEUMATIC SYSTEM

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DECLARATION

I declare that this thesis entitled "Predictive Functional Control with Reduced-order Observer Design using Particle Swarm Optimization for Pneumatic System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :..

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature	:...
Supervisor Name	: ....
Date	: ....

DEDICATION

Specially dedicated to:

My beloved parents; Abd Rahman bin Hj Musip and Naderoh bt Hj Abdul Aziz for their encouragement and blessings, my husband; Mohd Ihsan bin Abu Bakar and kids; Izz Ad Din bin Mohd Ihsan and Isha Irene bt Mohd Ihsan for their care and support. Thank you for always being here for me.

ABSTRACT

The pneumatic actuator is widely used in the automation industry and the field of automatic control, especially in positioning control, is highly in demand. However, the pneumatic actuator has difficulties to control due to the nonlinear factors such as air compressibility and friction. Therefore, this research will design a controller that focused on positioning control of Intelligent Pneumatic Actuator (IPA). This research aimed to develop a Predictive Functional Control using Reduced-Order Observer (PFC-ROO) to reduce the complexity of the pneumatic system. An optimization technique will be implemented in this project using Particle Swarm Optimization (PSO) algorithm. PSO is used to tuning the value of parameter time constant in Predictive Functional Control (PFC) to solve the problem for manual tuning. PSO will identify the best value of the parameter time constant associated with PFC for both PFC-ROO and PFC-FOO. Development of PFC-ROO algorithm is considered as a new control strategy for Intelligent Pneumatic Actuator (IPA) system for position control. This research is used the MATLAB/Simulink as a platform. The simulation results for both controllers will then be evaluated and validated using Data Acquisition (DAQ) card with a real-time experiment. In the real-time experiment, the horizontal position will be tested with different loads. Then, the result has been compared and validated the performance based on transient response analysis with existing controller Predictive Functional Control with Full-order Observer (PFC-FOO). The development will be analyzed in terms of smaller steady-state error (e_{ss}), 0 overshoot (%OS), faster settling time (T_s) and rise time (T_r) in simulation and real-time experiment. The result shows that the new development of PFC-ROO with optimization technique offers better performance compared to existing controller PFC-FOO with PSO. The best result for PFC-ROO, e_{ss} is 0.11 mm, %OS is 0%, T_s is 0.9247 seconds and T_r is 0.6620 seconds when time constant equal to 0.9023 where the best result for PFC-FOO when time constant equal to 0.9062 the e_{ss} is 0.25 mm, OS is 0%, T_s is 0.9192 seconds and T_r is 0.6638 seconds. The results revealed that the new method can reduce error by up to 56% of steady-state error.

ABSTRAK

Penggerak pneumatik digunakan secara meluas dalam industri automasi dan bidang kawalan automatik, terutamanya dalam kawalan kedudukan mempunyai permintaan yang tinggi. Walau bagaimanapun, penggerak pneumatik mempunyai masalah untuk mengawal kerana faktor-faktor tidak linear seperti kemampatan udara dan geseran. Oleh itu, penyelidikan ini akan merancang pengawal yang memberi tumpuan kepada Penggerak Pneumatik Pintar (IPA). Penyelidikan ini bertujuan untuk membangunkan Kawalan Fungsian Ramalan menggunakan Pemerhati Mengurangkan Perintah (PFC-ROO) untuk mengurangkan kerumitan sistem pneumatik. Teknik pengoptimuman akan dilaksanakan dalam projek ini dengan menggunakan algoritma Pengoptimuman Kerumutan Zarah (PSO). PSO digunakan untuk menala nilai pemalar masa parameter dalam Kawalan Fungsian Ramalan (PFC) untuk menyelesaikan masalah penalaan manual. PSO akan mengenal pasti nilai terbaik parameter pemalar masa yang dikaitkan dengan PFC untuk kedua-dua PFC-ROO dan PFC-FOO. Pengembangan algoritma PFC-ROO dianggap sebagai strategi kawalan baru untuk sistem Penggerak Pneumatik Pintar (IPA) untuk kawalan kedudukan. Kajian ini menggunakan MATLAB / Simulink sebagai platform. Hasil simulasi untuk kedua-dua pengawal akan dinilai dan disahkan menggunakan Kad Pengambilalihan Data (DAQ) dengan ujian masa nyata. Dalam ujian masa nyata, kedudukan mendatar akan diuji dengan beban yang berlainan. Hasilnya telah dibandingkan dan disahkan prestasi berdasarkan analisis tindak balas sementara dengan pengawal yang sedia ada Kawalan Fungsi Ramalan dengan Pemrhati Pesanan Penuh (PFC-FOO). Pengembangan akan dianalisis dari segi ralat keadaan stabil (e_{ss}), 0 peratus puncak terlajak (OS%), masa penyelesaian yang lebih cepat (T_s) dan waktu naik (T_r) dalam simulasi dan percubaan masa nyata. Hasilnya menunjukkan bahawa pembangunan baru PFC-ROO dengan teknik pengoptimuman menawarkan prestasi yang lebih baik berbanding pengawal yang sedia ada PFC-FOO dengan PSO. Keputusan terbaik untuk PFC-ROO ialah e_{ss} bersamaan 0.11 mm,% OS adalah 0%, Ts ialah 0.9247 saat dan Tr ialah 0.6620 saat masa malar bersamaan dengan 0.9023 di mana hasil terbaik untuk PFC-FOO apabila masa tetap bersamaan dengan 0.9062 adalah 0.25 mm, OS adalah 0%, Ts ialah 0.9192 saat dan Tr ialah 0.6638 saat. Hasilnya mendedahkan bahawa kaedah baru boleh mengurangkan kesilapan sehingga 56% daripada ralat keadaan mantap.

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LIST OF ABBREVIATIONS

ARX	-	Auto-Regressive with Exogenous Input
DAQ	-	Data Acquisition
IPA	-	Intelligent Pneumatic Actuator
MPC	-	Model Predictive Control
PFC	-	Predictive Functional Control
PFC-FOO	-	Predictive Functional Control using Full-order Observer
PFC-ROO	-	Predictive Functional Control using Reduced-order Observer
PI	-	Proportional-Integral
PID	-	Proportional-Integral-Derivative
PSO	-	Particle Swarm Optimization
PSoC	-	Programmable System on Chip

LIST OF SYMBOLS

Ψ	-	Time constant
e_{ss}	-	Steady-state error
Kob	-	Gain observer
OS	-	Overshoot
T_s	-	Settling time
T_r	-	Rise time

LIST OF PUBLICATIONS

Journal Paper

1. Azira, A.R., Osman, K., Samsudin, S.I., and Sulaiman, S.F., 2018. Predictive Functional Controller (PFC) with Novel Observer Method for Pneumatic Positioning Control. *Journal of Telecommunication, Electronic and Computer Engineering*, Vol 10, No 2-6, pp. 119-124. (Scopus)

Conferences

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CHAPTER 1

INTRODUCTION

1.1 Research background

Actuators are the mechanical or electro-mechanical device that widely used in industries for automation applications. Actuators type can be divided by the power they use. The actuator may be powered by electric current, pressurized fluid or compressed air pressure. Hydraulic actuator uses the power of hydraulics to generate mechanical action. The fact that liquids incompressible make a hydraulic actuator very powerful. The hydraulic power can be applied to one or both sides of a piston.

Pneumatic systems and hydraulic system are similar. Pneumatic system compressed air to transmit and control energy compared to a hydraulic system that used hydraulic fluid. Pneumatic systems are an absolute favourite for industrial companies compared to the hydraulic system because they can be built using lighter and cheaper materials but in industrial equipment, hydraulics are most suitable to suit their power and control. Since pneumatics, an important role in the industries in the performance of mechanical work area and many advantages of transmitting energy and control functions in the system, much development of automation solutions has been used the pneumatic system. One of the advantages is clean, this is very important in the textile, medicine and food industries where clean conditions are required. Mostly in food applications used a pneumatic system more often than others because there is less chance for contamination.

Pneumatic systems are one of the most commonly known in engineering and automation industries. Both industries are growing quickly and the same goes for the pneumatic system as well. The most frequently used pneumatic system in sectors where distinct kinds of pneumatic system offer distinct features. Different pneumatic systems involve varying controller types to get a better response. Therefore controller design has become essential as distinct pneumatics have been developed. For example, packaging and manufacturing sector requires precise, repetitive movement and pneumatic systems are suitable to meet the applications.

A pneumatic actuator system is a tool that converts energy from compressed air into mechanical movement. The pneumatic actuator was mostly applied due to their advantages such as lightweight, high power-to-weight ratio, comparatively low cost, easy to maintain, and having simpler structure compared to other actuators. Pneumatic is related to pressurized gas to produce mechanical motion. Nowadays, the pneumatic system becomes more complex hence leads to the development of an intelligent pneumatic system.

In the 20th century, complex and intelligent pneumatic systems have been rapidly developed. The difficulties in controlling pneumatic actuators are mostly due to nonlinearities effect of the system. Since then, for multiple automation applications and industrial purposes, many improvements have been made to the pneumatic actuators. It includes the required precision and efficiency and the quantity of force for each specific implementation. The intelligent pneumatic plant used in this research was referred to the prior job performed by (Osman et al., 2014). A Predictive Functional Control with Full-order Observer (PFC-FOO) has been developed here as a new pneumatic system approach. The researcher was combining the Predictive Functional Control (PFC) with observer which is a full-order observer.

The researcher was chosen PFC because of the high-quality control performance with improved rise time, precise tracking, robust stabilization and fast response. PFC has the same approach with all MPC strategies, such as prediction of future outputs and calculation of the manipulated variables for optimal control. The other benefits of the PFC controller are easy to understand, implement and tuning. This is because of PFC has a simple algorithm and use an internal model for the on-line prediction of the future system's behaviour. PFC also introduces a coincidence point and a prediction horizon; so that a manipulated variable is identified once during every control phase and the model value and reference trajectory meet at the coincidence point.

Then, with the advantages of PFC, the researcher was designed observers incorporated with PFC using MATLAB/Simulink and Data Acquisition System (DAQ) real-time control between the computer and the pneumatic actuator. The Predictive Functional Control with Observer (PFC-FOO) algorithm was applied to Ankle-Foot Rehabilitation Exerciser (AFRE) device using the IPA system. PFC-FOO algorithm was selected as a control strategy for IPA to overcome the real-time characteristics due to difficulties in controlling the position, force and stiffness in the IPA system.

This research is aimed to design PFC with reduced-order observer (PFC-ROO) for positioning control system. Then, the performance will be validated with existing PFC-FOO based on transient response analysis. A new method to simplify the design of pneumatic positioning system is proposed. This new approach also will decrease the system's complexity. To optimize the controller parameters, an optimization technique method of the Particle Swarm Optimization (PSO) algorithm was used in tuning the time constant (Ψ) parameter for both PFC-FOO and PFC-ROO because of its simplicity in implementation, performance and popularity in engineering applications. PSO was inspired by the natural behaviour of animals in forming a swarm. PSO is used to find the best value of the time constant (Ψ) in Predictive Functional Control (PFC) to get optimum response from the system. The previous researcher used a reference trajectory to get the value of parameter time constant (Ψ) in PFC. Reference trajectory has several steps to follow where the value of the time constant (Ψ) are manually select and test the output to know that the value gives an optimum performance or not, in other words, is "trial and error" method. The controller design will be focused on the position control and will be tested in simulation and real-time experimental to evaluate the performance of the proposed controller. Controller performance evaluation was simulated in MATLAB/Simulink and validated through real-time experiments using National Instrument (NI) devices and Programmable System on Chip (PSoC) microcontroller. To test the controller robustness and performance, the load will be attached to the IPA system in a horizontal position.