GENERALIZED PREDICTIVE CONTROL APPROACH FOR A MODIFIED SINGLE ACTING PNEUMATIC CYLINDER

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A thesis submitted in fulfilment of the
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I declare that this thesis "*Generalized Predictive Control Approach for a Modified Single Acting Pneumatic Cylinder*" is the result of my own research except as cited as in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Specially dedicated to my beloved family especially
my mother Latifah binti Abu talib for her
endless prayer, encouragement and blessings

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ABSTRACT

Pneumatic actuator is a device that converts air pressure to possible motions such as linear and rotary motion. Although the pneumatic actuator offers many advantages it is difficult to control. This is due to the nonlinearities involved such as friction and air compressibility. The equipment used in this research is the Intelligent Pneumatic Actuator (IPA). Previously, Proportional-Integral (PI) has been used as the controller for the IPA. Based on the previous result, a controller called generalized predictive controller (GPC) is proposed. Compared to PI, this controller has the capability to take into account the nonlinearity factor which is very important in this research. There are two types of GPC proposed in this research which are GPC with First Order Time Delay (GPC-FOTD) and GPC with Higher Order (GPC-HO). This research starts with the implementation of PI, GPC-FOTD and GPC-HO controllers for position and force control in simulations. Then, the simulation result is validated with the real-time experiments. There are two experiments for position control, which are position control with and without loads and one experiment for force control. Then, a Haptic Pneumatic Device (HPD) is developed in order to emulate a spring by combining the position and force control. By implementing the spring characteristic to the pneumatic device, a human machine interaction concept is applied to the device. In summary, GPC-FOTD shows better performance compared to GPC-HO and PI in terms of stability and better response for position control. For force control the GPC-HO shows better performance compared to other controllers in terms of tracking and accuracy. Then for the spring characteristic implementation, response of force versus displacement is presented where the results show stiffness coefficient (K_s) is directly proportional to the output force generated. This device together with GPC controller are capable of giving better results in terms of spring characteristic emulation control compared to the previous research on IPA. These results and application hopefully can be used to help people such as in rehabilitation sector, as exercise equipment and entertainment tools as well as comparison data for other controller development.

ABSTRAK

Penggerak pneumatik adalah alat yang menukarkan tekanan udara kepada beberapa gerakan seperti gerakan linear dan berputar. Walaupun penggerak pneumatik menawarkan banyak kelebihan ia adalah sukar untuk dikawal. Ini adalah disebabkan oleh faktor tak lelurus yang terlibat seperti geseran dan kemampatan udara. Alat yang digunakan dalam kajian ini adalah Pneumatik Aktuator Pintar (IPA). Sebelum ini, Proportional-Integral (PI) telah digunakan sebagai pengawal untuk IPA. Berdasarkan keputusan kajian, pengawal yang dipanggil Pengawal Ramalan Umum (GPC) dicadangkan sebagai pengawal baru. Berbanding PI, pengawal ini mempunyai keupayaan untuk mengambil kira faktor tak lelurus dan ianya adalah penting dalam kajian ini. Terdapat dua jenis GPC yang dicadangkan dalam kajian ini iaitu GPC dengan Kelewatan Masa Peringkat Pertama (GPC-FOTD) dan GPC dengan peringkat yang Lebih Tinggi (GPC-HO). Kajian ini bermula dengan pelaksanaan PI, GPC-FOTD dan pengawal GPC-HO bagi kedudukan dan kuasa kawalan dalam simulasi. Kemudian, hasil simulasi disahkan dengan eksperimen masa nyata. Terdapat dua eksperimen untuk kawalan kedudukan, iaitu kawalan kedudukan dengan dan tanpa beban dan satu eksperimen untuk kawalan daya. Kemudian, satu Alat Haptik Pneumatik (HPD) dihasilkan untuk menghasilkan satu ciri emulasi spring dengan menggabungkan kawalan kedudukan dan kuasa. Dengan melaksanakan ciri spring untuk peranti pneumatik, satu konsep interaksi mesin manusia dapat diadaptasikan ke dalam peranti. Ringkasnya, GPC-FOTD menunjukkan prestasi yang lebih baik berbanding dengan GPC-HO dan PI dari segi tindak balas yang stabil dan lebih baik untuk kawalan kedudukan. Untuk kawalan daya GPC-HO menunjukkan prestasi yang lebih baik berbanding dengan pengawal lain dari segi pengesanan dan ketepatan. Kemudian untuk pelaksanaan ciri spring, tindak balas tenaga melawan anjakan dibentangkan. Keputusan menunjukkan pekali pelembut (K_s) adalah berkadar langsung dengan daya keluaran. Peranti ini bersama-sama dengan pengawal GPC mampu memberi hasil yang lebih baik daripada segi kawalan emulasi ciri spring berbanding dengan penyelidikan sebelumnya dengan IPA. Keputusan dan aplikasi ini diharapkan boleh digunakan untuk membantu orang ramai seperti dalam bidang pemulihan, alat latihan dan alat hiburan serta sebagai data perbandingan untuk pembangunan pengawal yang lain.

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LIST OF ABBREVIATIONS

HPD	-	Haptic Pneumatic Device
HMI	-	Human machine interaction
K_s	-	Stiffness coefficient
GPC	-	Generalized Predictive Controller
PSoC	-	Programmable System on Chip
PI	-	Proportional-Integral
DAQ	-	Data Acquisition
PASS	-	Pneumatic Actuated Seating System
PC	-	Personal Computer
I^2C	-	Inter-Integrated Circuit
LED	-	Light-Emitting Diode
DC	-	Direct Current
PWM	-	Pulse Width Modulation
MPWM	-	Modified Pulse Width Modulation
PID	-	Proportional-Integral-Derivative
SMC	-	Sliding Mode Controller
MIMO	-	Multiple Input Multiple Output
ANFIS	-	Adaptive Neural Fuzzy Inference System
MPC	-	Model Predictive Controller
MPHC	-	Model Predictive Heuristic Control
MAC	-	Model Algorithm Control
DMC	-	Dynamic Matrix Controller
EHAC	-	Extended Horizon Adaptive Control
EPSAC	-	Extended Predictive Control Self Adaptive Control
GMV	-	Generalized Minimum Variance
MV	-	Minimum Variance
SCADA	-	Supervisory Control And Data Acquisition

SISO	-	Single-input/single-output
ARX	-	Autoregressive Model with External Input
BTCS	-	Brake Based Vehicle Traction Control
USM	-	Ultrasonic Motors
DOF	-	Degrees Of Freedom
PHI	-	Pneumatically Driven Haptic Interface
ARMAX	-	Autoregressive Moving Average with Exogenous Inputs
FOTD	-	First order with time delay
CARIMA	-	Controller Auto-Regressive Integrated Moving Average
HO	-	Higher Order model
IAE	-	Integral Absolute Error
ISE	-	Integral Square Error

LIST OF SYMBOLS

$\hat{y}$	-	Prediction output of the system
y	-	System output
w	-	Reference set point
$E\{\}$	-	Prediction set
u	-	Control signal
N_1	-	Minimum prediction horizon
N_2	-	Maximum prediction horizon
N_u	-	Control horizon
δ	-	Weighting factor
λ	-	Weighting factor
F	-	Generated output force
K_s	-	Stiffness coefficient
x	-	Displacement.
F_d	-	Driving force,
F	-	Applied force,
F_f	-	Frictional force,
m	-	Mass of the piston
$\ddot{x}$	-	Acceleration
A_1 , A_2	-	Corresponding cross sectional area in chamber 1 and 2
τ_d	-	Dead time
T_s	-	Sampling time
a, b	-	Parameter for FOTD model.
t_1	-	The time when the output reaches 28.3% of its steady state value
t_2	-	The time when the output reaches 63.2% of its steady state value
A, B	-	The polynomial for different backward shift operator

n	-	An integer,
$x(t)$	-	Disturbance.
$e(t)$	-	Zero mean white noise,
C	-	Noise polynomial
α	-	An adjustable value that influence the dynamic response of the system
K_p,	-	Tuning parameters.
K_i	-	Tuning parameters.
K_d	-	Tuning parameters.
T_R	-	Rise time
$\%OS$	-	Percentage of overshoot
$\%e_{SS}$.	-	Percentage of steady state error
C_s	-	Control signal for PWM conversion
T_S	-	Settling time

CHAPTER 1

INTRODUCTION

1.1 Overview

Pneumatic is a device that used air pressure as it power source. It converts the air pressure into a possible motion such as linear and rotary. Pneumatic actuator have been largely used in the industries and also actively used for research purpose. This is due to the advantages that the pneumatic actuator offers such as high power-to-weight ratio, relatively low cost, easy to maintain, lighter, and have simple structure compare to other actuators that available in the market [1]. In addition, the pneumatic actuator also is an environmental friendly device because it used air [2]. Example of pneumatic application such as to position controls applied in robotic manipulator, loading/unloading systems, air balance systems and gripper. Despite of all the advantages compared to electrical actuator used in robot and machines, it is difficult to control. This is due to the nonlinear factor involved such as the nonlinearity of the valve, compressibility of air and friction [3]. Therefore, many researchers put their effort in order to make the pneumatic actuator controllable for position and force control by proposing complex controller, new control strategies and etc. [3].

Pandian et. al [2] proved that air motor can be used as an alternative for electric powered motor. Although it is difficult to control pneumatic motor compared to electric motor, with certain control approach a better results can be achieved in terms of high accuracy, low steady state error and fast response.

Pneumatic actuator can be divided into two categories which are piston type and rotary type. Both of this actuator type uses air pressure as its power source. From the historical development, the development of the pneumatic actuator were created since the 16th century [4]. Since then, there are many developments regarding the pneumatic actuator in order to suit different automation, industry and applications. Now at the 20th century, the pneumatic actuator has evolved with complex and better sensors. For example [4] develop an intelligent pneumatic actuator with combination of different micro precision sensors and valve. This later on was applied to an application called Pneumatic Actuator Seating System [4]. The same actuator from the research will be used in this research however with different controller algorithm and methodology.

1.2 Problem Statement

1. The pneumatic actuator is difficult to control due to the nonlinear factor involved [3].

2. Although result from the previous work is good with ability to do tracking and fast response, further improvement can be done such as low transient response, higher accuracy and better tracking [4].

1.3 Research Objectives

The objectives of this research are:

1. To design a Generalized Predictive Controller (GPC) for pneumatic cylinder position and force control.

2. To compare the GPC controller for position control and force control performance with existing PI (Proportional-Integral) controller in simulation and real time experiment.

1.4 Scope of Work

The scopes of this research are as below:

1. The controller development is using MATLAB-Simulink as the platform.
2. The optimization of the GPC controller will be based on trial and error and past knowledge of the plant. Although the optimization is based on trial and error, certain guideline is follow which will be explained in Chapter 3 section 3.4.1.
3. The controller performance will be based on ISE and IAE. Lower ISE and IAE will resulted in good control performance in terms of lower cumulative error.

1.5 Thesis Outline

Chapter one is discussing about the thesis overview, problem statements, research objectives and scopes of this research. Then, chapter two present the literature review regarding the intelligent pneumatic development, GPC history, position control, force and Spring characteristic and lastly about human machine interaction. Chapter 3 is discussing about the research methodology used in this research from the start until the results meet the objective requirement. Next is chapter 4, which is the controller approach. In this chapter, the GPC derivation PI controllers are discussed. Chapter 5 is the results and discussions. In this chapter, the research results for position and force control is presented. In addition, the device designed for spring characteristic implementation is also presented. Lastly, is chapter six which is the conclusion and recommendation. In this chapter, the thesis conclusion which reflected the thesis objective is presented. Meanwhile, for further improvement suggestion is presented in the recommendation.

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