UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PNEUMATIC ACTUATOR SYSTEM CONTROLLER DESIGN

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electrical Engineering Technology (Industrial Automation & Robotics) with Honours.

by

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This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering Technology (Industrial Automation & Robotics) with Honours. The member of the supervisory is as follow:

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ABSTRAK

Kelebihan sistem penggerak pneumatik seperti kos rendah, mesra alam, kebolehpercayaan yang tinggi dan nisbah kuasa-berat yang tinggi adalah antara sebab kegunaannya dalam industri automasi semakin bertambah banyak. Kelebihan-kelebihan tersebut telah memjadikan sistem penggerak pneumatik satu pilihan alternative selain daripada penggerak hidraulik dan motor servo elektrik dalam menyiapkan kerja automasi. Walau bagaimanapun, penggerak pneumatik mengalami cabaran untuk sampai di posisi yang ditetapkan dengan tepat disebabkan oleh daya geseran dan kebolehmampatan udara. Oleh itu, pengawal diperlukan untuk mengawal sistem supaya masalah ini dapat dikawallan. Sebelum pengawal boleh direkacipta, modal matematik perlu diambilkan. Modal matematik tersebut akan dibandingkan dengan data eksperimen untuk pengesahan dengan menggunakan *System Identification*. Selepas itu, pengawal PID, satu pengawal yang paling biasa digunakan dalam industri akan direkaciptakan untuk mengawal sistem. Hasilnya menunjukkan bahawa pengawal PI adalah pengawal yang berprestasi dengan paling baik di antara pengawal-pengawal berdasarkan PID. Prestasi pengawal tersebut masih boleh ditambahbaikkan berdasarkan keputusan dari perbandingan pengawal-pengawal berdasarkan PID. Jadi, pengawal Fuzzy Logic telah direkacipta bersama dengan PID untuk selesaikan masalah tersebut. Dari keputusan perbandingan prestasi di antara pengawal Fuzzy PID, pengawal PID dan pengawal Fuzzy Logic, ia menunjukkan Fuzzy PID mempunyai prestasi yang lagi baik daripada pengawal PI manakala pengawal Fuzzy Logic gagal direkaciptakan. Pengawal Fuzzy PID tidak mempunyai terlebihan tembakan dan *settling time* yang lagi cepat daripada pengawal PI. Pengawal Fuzzy PID telah dibuktikan ia adalah pengawal yang paling kuat memandangkan ia dapat menahan perubahan yang lagi banyak dalam sistem daripada pengawal PI.

ABSTRACT

Pneumatic actuator system with advantages such as low cost, eco-friendly to environment, high reliability and high power to weight ratio are the reason to its wide application in the automation industry nowadays. These advantages support the pneumatic actuators appear to be the alternatives choice other than the hydraulic actuator system and electric servo motors to execute automated work. However, the highly non-linearities of pneumatic actuators due to the friction force and compressibility of air cause the actuators difficult to reach an accurate target position. Therefore, controller need to be employed to control the system for solving the problems. Before the controllers can be designed, the mathematical model of the system is obtained. The model is then compared with experimental data for validation by using System Identification. After that, PID controller, which is the most common used controller in the industry is designed to control the system. The outcomes show that PI controller has the best performance among the PID base controllers. The performance of the controller is still able to be improved based on the PID base controller performance comparison results. So, Fuzzy Logic controller is designed with PID to solve the problem. From the results of performance comparison between Fuzzy PID, PID and Fuzzy Logic, it shows that Fuzzy PID has the best performance compared to PI controller while Fuzzy Logic controller is failed to be designed. Fuzzy PID controller has 0% overshoot and faster settling time than PI controller. The Fuzzy PID controller is proven as a more robust controller since it can withstand more load changes in the plant than PI controller.

DEDICATION

To my beloved family

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Ooi Wei Zheng, Melaka

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LIST OF SYMBOLS

de/dt or $\Delta e(k)$	Derivative of Error
$e(k)$	Error signal
e_{ss}	Steady-state error
K_p	Proportional gain
K_i	Integral gain
K_d	Derivative gain
$K_{p\ min}$	Minimum proportional gain
$K_{i\ min}$	Minimum Integral gain
$K_{d\ min}$	Minimum Derivative gain
$K_{p\ max}$	Maximum proportional gain
$K_{i\ max}$	Maximum integral gain
$K_{d\ max}$	Maximum derivative gain
$k(e)$	Nonlinear gain
N	Filter coefficient
n_a	Order of polynomial A(q)
n_b	Order of polynomial B(q)+1
n_k	Input-output delay
T_R	Rise time
T_S	Settling time
$u(t)$	Output signal
%OS	Percentage of overshoot

LIST OF ABBREVIATIONS

A/D	Analogue to Digital
ARMAX	AutoRegressive Moving Average with Exogenous input
ARX	AutoRegressive with Exogenous input
B	Big
BJ	Box Jenkins
D/A	Digital to Analogue
DSC	Dynamic Surface Control
DSP	Digital Signal Processing
DZC	Dead Zone Compensator
E	Error
EC / dError	Change in Error / Derivative of Error
FRL	Filter Regulator Lubricator
FPID	Fuzzy Proportional-Integral-Derivative
GMVC	Generalized Minimum Variance Controller
GUI	Graphic User Interface
LQR	Linear Quadratic Regulator Optimal Controller
M	Medium
MB	Medium Big
MDSC	Modified Dynamic Surface Control
MISO	Multiple Input Single Output
MPID	Modified Proportional-Integral-Derivative
MS	Medium Small

MVC	Minimum Variance Controller
NB / BN	Negative Big
NM	Negative Middle
NPID	Nonlinear Proportional-Integral-Derivative
NS	Negative Small
OE	Output Errors
P	Proportional
PB	Positive Big
PD	Proportional-Derivative
PI	Proportional-Integral
PID	Proportional-Integral-Derivative
PM	Positive Middle
PS	Positive Small
PSO	Particle Swarm Optimization
PWM	Pulse Width Modulation
S	Small
SN-PID	Self-regulation Nonlinear Proportional-Integral-Derivative
Z	Zero
ZE	Zero Error
ZOH	Zero Order Hold

CHAPTER 1

INTRODUCTION

1.1 Background

Pneumatic come from the late ancient Greek word ‘pneuma’ in about 1650s, which means it related to air. Pneumatic is an old ancient technology, which the blowgun is invented by ancient people for hunting purpose. With human lungs’ capacity on that time, the pressure produced is at around 1-3 psi. In around 3000 B.C., the first manually operated compressor is finally invented to help in providing air to light up the fire. Pneumatic is getting more important when entering the bronze age, where human started to use metal in their life. After 1950s, the pneumatic system is brought into the factory to take over the human energy in production line and are widely spread around the world nowadays (Zhong and Zhao, 2019);(Trujillo, 2015).

The role of pneumatic actuator system in automation industry are getting more important nowadays, it is applicable in the light or medium duty application due to the cheaper cost, easy found material, high generative force, large power to weight ratio and safe to operate this system. Pneumatic system is also an eco-friendly system with low maintenance fee required (Lee, Choi and Choi, 2002);(Yamaguchi *et al.*, 2012);(Zhang *et al.*, 2019); (Jang *et al.*, 2012); (Raghuraman, Kumar and Kalaiarasan, 2017);(Claeyssen *et al.*, 2007). Pneumatic actuator system is widely used in the automation sector such food industry, aviation industry and transportation industry. Pneumatic system is a system that formed up by an air compressor, regulators and gauges, check valve, buffer tank, feedlines, directional valves and actuator. It has similar characteristic as the hydraulic system, but instead of using hydraulic fluid, the pneumatic system is using compressed air to retract or advance the actuator(Seabra, 2017);(Mohammed and Suleiman, 2001).

Even though the pneumatic actuator system seems to be an easy operating system with various advantages, yet it still has some disadvantages in its application. The friction and compressibility of the air make the pneumatic actuator difficult to control. These difficulties cause the actuator couldn't reach the expected position accurately and may be lag and delay in response(Nazari and Surgenor, 2016);(Shilin, Gribkov and Golubev, 2017). Due to the disadvantages, therefore, implementation of controller is needed in order to optimise the performance of pneumatic actuator system. There are different types of controller developed by researchers since application of pneumatic actuator system in industry getting wider.

Previous studies with using different approaches such as conventional Proportional-Intergal-Derivative (PID) controller and Fuzzy Logic controller on the pneumatic actuator system start to get attention and increase its researches at around 1990s(Buckley, 1992);(Unar, 1995). Hybrid of the Fuzzy Logic controller and PID controller started to be researched on 1998 but only start to popular in the pneumatic actuator positioning sector after 2008(Mann, Hu and Gosine, 1999);(dos Santos Coelho and Coelho, 1999). In the past 15 years, the performance of the pneumatic positioning actuator is significantly improved with aid of all those types of controller. Nowadays in the industry, PID controller is still the most widely used controller due to its simplicity and low cost, although it couldn't be used to handle the highly non-linear system(Yun Li, Kiam heong Ang, 2007).

Some previous researchers have already done the similar research to compare the performance of pneumatic actuator and proposed idea to try to overcome the performance of actuator in nonlinear environment. However, the main problem faced by pneumatic actuator is the dead zone and uncertainties in the system such friction of cylinder and actuator which effect of these source of problems is still there even with previous researchers' controller is implemented. Therefore, continuous study needs to be carried out to analyse and overcome the problems.

1.2 OBJECTIVE

1. To conduct an experiment for obtaining mathematical model of the pneumatic plant.
2. To design PID base controller, Fuzzy Logic controller and hybrid fuzzy PID controller using the developed system.
3. To analyse and compare performances of each controller of the developed system.

1.3 PROBLEM STATEMENT

The pneumatic actuators are powered by compressed air to actuate to a certain position in the plant. Due to the compressibility of air, the pneumatic positioning actuators are having parametric uncertainties which cause the actuator couldn't reach target position accurately. Modelling the pneumatic actuator system is the most important step before controller can be designed and an appropriate approach needs to be chosen to model the system. By implement a controller into the system, the parametric uncertainties would be overcome to obtain a better system performance. Different performance would be observed with different controller implemented. Thus, System Identification need to be used to analyse the system performances accurately and the controllers need to be designed by using an appropriate method for performance analysis and performance comparison purpose.

1.4 SCOPE

1. Determine the mathematical model of the pneumatic actuators system by using System Identification toolbox in MATLAB. The validation of the results will be proven with experimental data. Optimisation of system with different controller and the comparison of model with system identification will also be performed in this project. The mathematical model will be used to design and simulate PID, Fuzzy Logic and hybrid PID Fuzzy controller.
2. The experiment is performed with different advance distance of actuator and different load weight, until the maximum distance of 300mm and maximum weight of 3kg.
3. The performance of the pneumatic actuator positioning system with different types of controller will be compared. In this study, the PID base controller is used to compare with hybrid Fuzzy PID controller and Fuzzy Logic controller.

1.5 Project Outline

The organisation of this project is as stated below:

The second chapter of this study collected all the literature review about the pneumatic actuator positioning system. The work done, techniques and achievement by previous researchers is reviewed, studied and identified. The techniques used by previous researchers is summarised and the controllers used for comparison is identified at the last part of this chapter.

The third chapter started with the workflow of this project. Work to do at each stage is explained clearly at this chapter. The equipment used to obtain the data and to do the simulation and comparison is also introduced in this chapter. The process of verifying the data by using System Identification will be clearly explained. The procedure and techniques to design the controllers in ideal condition is the last part of this chapter.

The fourth chapter is briefly explained about the design of each controller and simulation results of the controllers. The simulation results are then implemented onto the real plant to obtain the controllers' performance in real plant which is the pneumatic actuator positioning system. The implementation performance results of the controllers are used to compared with each other to identify the best controller. Lastly, the robustness of the controllers is tested by applying different load on the plant.

The fifth chapter summarizes all the finding in this study and conclusion of the performance comparison. Future work suggestion is provided at the end of this chapter.