DESIGN OF SLIDING MODE CONTROLLER FOR ROBUST TRACKING OF PNEUMATIC SYSTEMS

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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I hereby, declared this report entitled "Design of Sliding Mode Controller For Robust Tracking Of Pneumatic Systems." is the results of my own research except as cited in reference.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for Degree of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

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ABSTRACT

The widespread use of pneumatic actuator systems in the automation industry today is due to their many advantages, which include cheap cost, environmental friendliness, high reliability, and a high ratio of power to weight. As a result of these benefits, pneumatic actuators are increasingly being considered as viable alternatives to hydraulic actuator systems and electric servo motors for automating processes. Because of the high nonlinearities of pneumatic actuators, it is difficult to achieve accurate tracking performance. Because of this, a controller is required to regulate the system and thereby solve the high nonlinearity problem. The mathematical model of the system must first be constructed before the controllers can be created by using MATLAB software. The system model is next validated by comparing it to experimental data, which is accomplished with the use of the System Identification technique. Following that, three controllers have been designed, such as PID controller, SMC controller, and Pseudo-SMC. These three controllers will be simulated and tested on the real plant, and controller's performance will be measured in terms of maximum tracking error and RMSE with disturbance applied such as external load. The results show that SMC-based controllers can produce an average improvement of 87% in terms of maximum tracking errors and a reduction of 80% in terms of root mean square error (RMSE). Among the SMC-based controllers, pseudo-SMC controllers can reduce the chattering effect using a Fast Fourier Transform approach. However, the SMC controller can achieve a low percentage of load variation in terms of robustness. Overall, the Pseudo-SMC controller has superior robust tracking performance against the SMC controller and the PID controller.

ABSTRAK

Penggunaan sistem penggerak pneumatik yang meluas dalam industri automasi hari ini disebabkan oleh banyak kelebihannya, termasuk kos murah, keramahan alam sekitar, kebolehpercayaan yang tinggi, dan nisbah kuasa dan berat yang tinggi. Hasil daripada faedah ini, penggerak pneumatik semakin dianggap sebagai alternatif yang sesuai untuk sistem penggerak hidraulik dan motor servo elektrik untuk proses automatik. Kerana tidak linear penggerak pneumatik yang tinggi, sukar untuk mencapai prestasi penjejakan yang tepat. Oleh kerana itu, pengawal diperlukan untuk mengatur sistem dan dengan itu menyelesaikan masalah nonlineariti yang tinggi. Model matematik sistem mesti dibina terlebih dahulu sebelum pengawal dapat dibuat dengan menggunakan perisian MATLAB. Model sistem selanjutnya disahkan dengan membandingkannya dengan data eksperimen, yang dicapai dengan penggunaan teknik Pengenalan Sistem. Berikutan itu, tiga pengawal sudah direka bentuk, seperti pengawal PID, pengawal SMC, dan pengawal Pseudo - SMC. Ketiga-tiga pengawal ini akan disimulasikan dan diuji pada mesin sebenar, dan prestasi mereka akan diukur dari segi ralat penjejakan maksimum dan ralat punca min kuasa dua dengan gangguan berat luaran dikenakan pada mesin eksperimen. Hasil kajian menunjukkan bahawa pengawal berasaskan-SMC dapat menghasilkan peningkatan rata-rata 87% dari segi ralat penjejakan maksimum dan pengurangan 80% dari segi ralat punca min kuasa dua. Di antara pengawal berasaskan-SMC , pengawal pseudo- SMC dapat mengurangkan kesan signal bising menggunakan pendekatan Fast Fourier Transform. Walau bagaimanapun, pengawal SMC dapat mencapai peratusan variasi beban yang rendah dari segi ketahanan. Secara keseluruhan, pengawal Pseudo - SMC mempunyai prestasi penjejakan yang kuat terhadap pengawal SMC dan pengawal PID.

DEDICATION

For my beloved parents,
Who has been giving me strength
and providing me with moral, emotional, and financial support.

To my encouraging supervisor, Ir. Dr. Lokman,
Who has been a source of knowledge
and guidance for me throughout this project.

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LIST OF ABBREVIATIONS

ARX	-	Auto Regressive Exogenous
ARMA	-	Auto Regressive Moving Average
ARMAX	-	Auto Regressive Moving Average Exogenous
BJ	-	Box-Jenkins
DC	-	Direct Current
FRL	-	Filter, Regulator and Lubricator unit
FFT	-	Fast Fourier Transform
GM	-	Gain Margin
HOSM	-	High Order Sliding Mode
LMI	-	Linear Matrix Inequalities
MIMO	-	Multiple-Input-Multiple-Output
MRAC	-	Model Reference Adaptive Controller
MSSC	-	Multiple Surface Sliding Controller
NARX	-	Nonlinear Autoregressive Exogenous Model
OE	-	Output Error
PID	-	Proportional, Integral, Derivative
PSO	-	Particle Swarm Optimization
PWM	-	Pulse width Modulation
RLS	-	Recursive Least Square

RMSE	-	Root Mean Square Error
SI	**-**	System Identification
SMC	-	Sliding Mode Controller
SOSMC	-	Second Order of Sliding Mode Control
VSC	-	Variable Control Structure
2-DSMC	-	Discreet Second Order Sliding Mode Control

CHAPTER 1

INTRODUCTION

Pneumatic systems are power transmission systems that use compressed air as the working medium for the transfer of mechanical force. Their functioning is based on a concept that is similar to that of hydraulic power systems. When a prime mover produces mechanical energy, an air compressor turns that energy into primarily pressure energy in the form of compressed air. This chapter will present a project titled "Design of Sliding Mode Controller (SMC) for Robust Tracking of Pneumatic Systems." The project is about precision control development on the pneumatic actuator to input disturbance force. The selected precision control algorithm is a robust controller named "Sliding Mode Controller (SMC)" and is used to test the robustness tracking on the pneumatic actuator. The designed controller will be designed and numerically analysed using MATLAB software. The controller will be experimented with in this project by implementing the designed controller on the actual plant, and control performance will be evaluated based on this setup.

1.1 Background

Pneumatic actuators are extensively used in today’s industrial world because they are positively safe to operate, economical, simple to maintain, environmentally friendly, rapid-acting, and may be directly linked to the payload. However, they also have high-order time variant dynamics, which causes nonlinearities because of the high friction force, dead band owing to stiction force produced by the sealing ring of the cylinder, and dead time due to air compressibility, among other things. These nonlinearities make it difficult to adjust the actuator’s placement. Servo valves, rather than solenoid valves, were traditionally employed to operate pneumatic actuators.

To achieve a satisfactory outcome, a servo valve was employed in combination with a Sliding Mode Control (SMC) controller, and it was also used to compare linear and nonlinear control of an air pneumatic servo-drive. Because of the high precision manufacturing limits and the necessity for a built-in orifice area control circuit, earlier servo valves were sophisticated in form and huge in cost. Nowadays, servo valves are being replaced by on/off solenoid valves, which are more economical, tiny, and light weight, as well as recent improvements in valve technology, making them more desirable for application, despite the fact that they have a limited lifetime owing to valve wear and tear.

SMC is generally considered one of the most effective techniques for creating trustworthy controllers for complicated high-order nonlinear dynamic plants working in uncertain settings. The major advantages of sliding mode are that they are insensitive to plant parametric variability and have the capacity to reject disturbances, thereby minimising the requirement for accurate models. Because the sliding mode trajectory corresponds to a manifold with a lower size than the original system, the system’s order is decreased, enabling the designer to decouple and simplify the design processes.

Though SMC is a nonlinear control method that alters the dynamics of a nonlinear system, the unwanted occurrence of oscillations with a finite frequency and amplitude known as "chattering" is noticed in real implementations because of the discontinuity of control over the switching surface. SMC can manage system dynamics that aren’t precisely modelled, but it requires exact state information to create a sliding surface.

1.2 Problem Statement

Previous researchers, such as (Sy Salim et al., 2014), noticed that the study of pneumatic systems was challenging because of the high nonlinearity that existed in the system, such as the high air compressibility, the existence of friction force, and the factors determining mass flow rate. This increased complexity made it harder to get the system's uncertainty parameters, which led to severe difficulty when attempting to develop robust control of the pneumatic system. The existing problem of high nonlinearity in the system may lead to reduced robust tracking performance. In order to solve nonlinearity in pneumatic actuator systems, a controller such as a PID controller, adaptive controller, or sliding mode controller is required to regulate the system.

Therefore, the controller of a pneumatic system, which is most likely an independent nonlinear system, is designed as a Sliding Mode Controller (Perruquetti & Barbot, 2002), while applying the external load to the controller system is required to attain robust tracking performance from the actual plant.

1.3 Objectives

The objectives of this study are:

i. To determine the system model of a pneumatic system using system identification technique.
ii. To design an SMC controller for the servo pneumatic system.
iii. To analyse the controller performance in terms of maximum tracking error and root mean square error.
iv. To evaluate the SMC controller's robustness by applying additional loads to the servo pneumatic system.

Table 1.1 clarifies the relationship between problem statement and objective to make things simpler to see both relations.

Table 1.1: Relationship between problem statement and objectives

Problem statement	Objectives
High nonlinearity in pneumatic servo system	Objective 1 and objective 2 • Obtaining a new system model by using System Identification technique and applying it to the designed SMC controller.
Robust tracking performance	Objective 3 and Objective 4 • Analysing the designed controller with maximum tracking error and RMSE analysis. • Evaluate the controller robustness when applying additional load to the experimental plant system.

1.4 Scope of Study

The scopes of this project are:

i. Only limited to the actuator of the servo-pneumatic system.

ii. Analysis of the accuracy and robust tracking of the pneumatic actuator is based on 0.1 Hertz of sinusoidal wave input, with an amplitude of 60 mm.

iii. Variations of external loads from 0 kg until 9 kg with an increment of 1 kg are used for the robust analyses.

iv. Simulation will be performed by using MATLAB software, and the designed controller will be experimented into the actual plant setup.

v. Evaluation of the maximum tracking error and stability of the controller plant.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

An introduction to literature study on subjects relating to controller design and accurate positioning of machine tool applications is provided in this chapter. The positioning system under consideration is used in the production engineering fields and is the actuator of a servo-pneumatic actuator system. The first section of the chapter discusses the approaches to positioning systems that have been developed by prior researchers in the past. The next section is a review of the techniques for managing the system using several broad kinds of controllers that have been studied in the previous year. Finally, in the last portion of this chapter, a summary of the studies completed by past researchers will be provided.

2.2 Positioning system

According to (Das et al., 2013), one of the most difficult areas to control in pneumatic actuation seems to be the position control of the pneumatic actuation system and the overall functioning of the pneumatics system. Consequently, motion control for the pneumatic servo system is one of the most difficult aspects of the system. The use of pneumatic actuators in robotic manipulators and mechatronics applications has increased significantly. As a result, the demands for precise position tracking performance and erratic positioning between the two hard stop endpoints of the pneumatic actuator stroke have increased as well (Azahar et al., 2021), Figure 2.1 shows the basic structure of servo pneumatic positioning system. Diverse efforts have been undertaken to improve the design of control systems for pneumatic actuators, notably in position control.

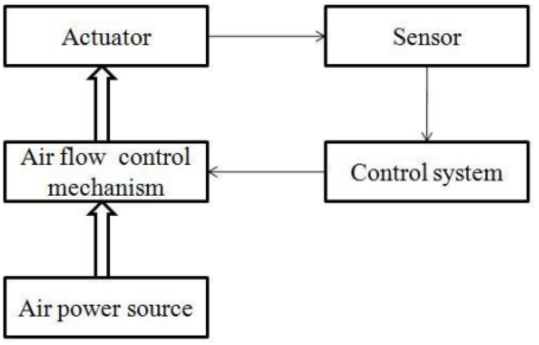

Figure 2.1 : Basic Structure of Servo Pneumatic positioning system

2.2.1 Servo pneumatic system

Actuators powered by pneumatics are employed in batch automation of sequences as well as continuous control (Saravanakumar et al., 2017). Traditionally, pneumatic actuators have been employed to move objects between two predetermined stops. With the help of electro pneumatic servo drives, it is possible to extend the capabilities of pneumatic drives and utilise them to operate in many positions. In general, this form of servo pneumatic technology employs a feedback-based closed-loop control method and has been illustrated in Figure 2.2.

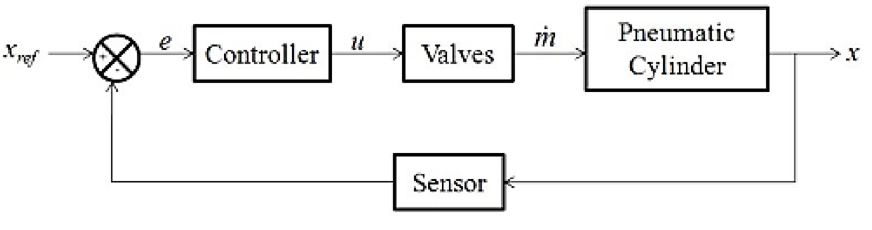

Figure 2.2: Control of pneumatic cylinder position by closed-loop feedback (Saravanakumar et al., 2017)