POSITION CONTROL USING FUZZY-BASED CONTROLLER FOR PNEUMATIC-SERVO CYLINDER IN BALL AND BEAM APPLICATION

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Specially dedicated to

my family for their encouragement and blessings,

my wife CK. Farhana for her support and care.

Thanks for always being there for me.

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ABSTRACT

Pneumatic actuator is widely used in the automation industry and in the field of automatic control due to its advantages such as high power to weight ratio, cost-effective and uses air as a clean medium to drive it. However, pneumatic actuator also has some drawback in control due to the nonlinear factors such as air compressibility and friction. Therefore, the purpose of this research is to design a controller that will control the position of the cylinder pneumatic stroke. Fuzzy Logic Control is proposed because of its simplicity in terms of less mathematical equation and also its performance in controlling the nonlinearities. Three different types of Fuzzy Logic controller were designed and compared to observe the performance of the controller in controlling the pneumatic actuator. An optimization method of the Particle Swarm Optimization (PSO) algorithm is used in tuning the fuzzy control parameter. PSO is used to find the best value of the parameter involved in the controller design. Both controllers and optimization method are designed using MATLAB/Simulink platform from position transfer function obtained by System Identification (SI) technique. Then, the simulation results are analyzed and validated with real-time experiment using the Data Acquisition (DAQ) card. The experiment has been done to the pneumatic actuator with different loads and positions target. A Pneumatic Ball and Beam System (PABBS) is proposed as the application of the position controller. The mathematical model of the system is developed and tested with simulation and experiments for its fast response and stability in controlling the ball movement. Results show that Proportional-Derivative Fuzzy Logic Controller (PD-Fuzzy) offers better control compared to other controllers in terms of stability and robustness for the pneumatic actuator and cascaded PD-Fuzzy controller gives better control compared with position and rate feedback controller for the PABBS application.

ABSTRAK

Sistem pneumatik banyak digunakan di dalam sektor industri automasi dan juga di dalam bidang kawalan automatik kerana kelebihan yang dimiliki seperti kuasa yang tinggi dinisbahkan kepada berat, kos yang efektif dan menggunakan udara yang bersih sebagai medium penggerak. Walau bagaimanapun, penggerak pneumatik juga terdapat beberapa kelemahan untuk mengawal disebabkan oleh tak lelurus yang terlibat seperti kemamapatan udara and geseran. Oleh itu, tujuan kajian ini adalah untuk mereka bentuk satu pengawal yang akan mengawal kedudukan lejang pneumatik silinder. Kawalan Logik Kabur adalah dicadangkan kerana kemudahan dari segi persamaan matematik yang kurang dan juga prestasi dalam mengawal tak lelurus. Tiga Kawalan Logik Kabur yang berbeza telah direka dan dibandingkan untuk melihat prestasi kawalan dalam mengawal penggerak pneumatik. Satu kaedah pengoptimuman algoritma Pengoptimuman Kerumunan Zarah (PSO) digunakan dalam mencari parameter yang sesuai. PSO digunakan untuk mencari nilai terbaik parameter yang terlibat dalam reka bentuk pengawal. Kedua-dua pengawal dan kaedah pengoptimuman direka menggunakan MATLAB/Simulink platform dari fungsi pemindahan kedudukan yang diperolehi dari teknik Sistem Pengenalan (SI). Kemudian, keputusan simulasi dianalisis dan disahkan dengan eksperimen masa nyata menggunakan kad Perolehan Data (DAQ) dengan beban dan kedudukan sasaran yang berbeza. Satu sistem pneumatik bola dan rasuk (PABBS) dicadangkan sebagai aplikasi pengawal kedudukan. Model matematik sistem ini dibangunkan dan diuji secara simulasi dan eksperimen untuk tindak balas yang cepat dan kestabilan dalam mengawal pergerakan bola. Keputusan menunjukkan bahawa Pengawal Logik Kabur Berkadar-Derivatif (*PD-Fuzzy)* memberi pengawal kawalan yang lebih baik berbanding dengan pengawal lain dari segi kestabilan dan kekukuhan untuk penggerak pneumatik dan pengawal *cascaded PD-Fuzzy* memberikan kawalan yang lebih baik berbanding dengan kedudukan dan pengawal maklum balas kadar untuk aplikasi PABBS.

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LIST OF ABBREVIATIONS

ARMAX	-	Auto-Regressive Moving Average with Exogenous
CAD	-	Computer –aided Design
DAQ	-	Data Acquisition
FIS	-	Fuzzy Inference System
FLC	-	Fuzzy Logic Control
GA	-	Genetic Algorithm
GPC	-	Generalized Predictive Control
IAE	-	Integral Absolute Error
ICT	-	Intelligent Chair Tool
IPA	-	Intelligent Pneumatic Actuator
ISE	-	Integral Squared Error
ITAE	-	Integral of Time Absolute Error
I/O	-	Input/ Output
LED	-	Light-emitting Diode
MF	-	Membership Function
MISO	-	Multiple Input Single Output
NN	-	Neural Network
PABBS	-	Pneumatic Actuated Ball and Beam System
PD	-	Proportional-Derivative
PI	-	Proportional-Integral
PID	-	Proportional-Integral-Derivative
PWM	-	Pulse Width Modulation
PSO	-	Particle Swarm Optimization
SI	-	System Identification
SISO	-	Single Input Single Output
TF	-	Transfer Function

CHAPTER 1

INTRODUCTION

1.1 Overview

The number of fields in which actuators are applied has increased over the past few years. Actuators can be categorized as piezoelectric, electromagnetic, pneumatic, and hydraulic actuators, which range in size and force from nano to mega range [1]. Actuators are used for automation applications in many industries. In the process control plants, actuators regulate the respective material, mass or energy flows by adjusting valves, flaps or slide valves [2]. In home application, actuators are applied in human friendly robot, and other robot's application [3, 4]. They are also used in micro machines, medical application and in special environment [4].

The latest technology has now reached actuators as they become part of intelligent field devices [1]. While the conventional (normal/basic) actuator requires fast rotation, strong, efficient, and precise, the requirements for new actuators also have become numerous and in many varieties depending on their application. For example, micro robots and active catheters require powerful micro actuators, whereas nursing robots and pet robots require actuators with intelligence, force control, and safety. On the other hand, the motions of actuators have been changing where not only rotation and linear motion are applied; but motions with multiple degrees of freedom and bending motions are also needed. These motions correspond to the contacting objects, for example, actuators that have several applications. Currently, there are various applications that require new actuators as part of the system such as methods of communication between human and machines which are urgently desired by engineers; therefore, a new intelligent actuator for such applications is expected.

In this research, a pneumatic intelligent actuator (is then called as the pneumatic-servo cylinder) is selected because of its advantages such as communication ability and local control functions, while reducing the number of cables connected, as well as having more delicate and high-performance actuator motions. This actuator has a different characteristic because most of the pneumatic actuator has full extend and contract while this actuator, the pneumatic stroke can be control accordingly. A particularly well suited application for pneumatic actuators is the position control of robotic manipulators, end effectors, pick and place system, and grippers, where stiff and lightweight structures are critical. Unfortunately, pneumatic actuators are subjected to high friction forces, dead time (due to the compressibility of air), valve dead zone problems, mass flow rate parameters, the compliance variation and the generating force [5, 6]. These nonlinearities make accurate position control of a pneumatic actuator is difficult to achieve [7].

As a result, a considerable amount of research work has been devoted to the development of various position-control systems for pneumatic actuators [8-11]. The controller will be focused on the position control and will be tested in simulation and experimental (real-time experiment) to see the performance of the controller. In order to test the controller robustness and performance, an external load will be attached at the end effector of the pneumatic. To this end, a pneumatic actuated ball and beam system will be proposed as a linear stabilizing system. The system will use the pneumatic-servo cylinder as the actuator to move the ball along the beam. The ball and beam system is viewed as a benchmark in control engineering setup where the underlying concept can be applied in the stabilization problem for diverse system such as the balance problem dealing with goods to be carried by a moving robot, the spaceship position control systems in aerospace engineering [12, 13] and to test pneumatic actuator to its limit.

The proposed controller method is Artificial Intelligent, which will be using Fuzzy Logic Control (Fuzzy-based controller) and will be validated with different controllers by other researchers [14, 15]. An optimization method of the Particle Swarm Optimization (PSO) algorithm is used in tuning the parameter. PSO is used to find the best value of the parameter (scaling factors) to get an optimum response. Previous researcher has tried to implement this intelligent actuator in physical human-machine interaction [4, 16, 17]. By using position control as the main objective, this research will implement it on Pneumatic Actuated Ball and Beam System (PABBS).

1.2 Motivation

Pneumatic systems are widely known in the field of engineering and industries. Both sectors are fast emerging and the same also goes to the pneumatic system. Pneumatic system evolves to suit the demand of the industries and different types of pneumatic system have different characteristics. Different pneumatic systems need different types of controller to give a better response. Therefore controller design is important as different pneumatic been developed.

1.3 Problem Statement

Pneumatic cylinders are used to provide linear motion in machines and tools in industrial operations. Some key advantages of pneumatic cylinders are regarding their speed, high power to weight ratio, versatility, cost effectiveness, and the use of a clean medium to drive them. In spite of these advantages, it is difficult to get accurate position control for pneumatic actuators due to compressibility of air, high friction forces and valve dead zone problems [18]. Position control is important in determining the accuracy and response of the pneumatic cylinder which is very critical in the application of stabilizing system (i.e. ball beam system). Therefore, this research is focused on the position controller for pneumatic-servo cylinder using Fuzzy-based controller.

The ball and beam system is chosen because the system is one of the most popular and important benchmark systems for studying control systems [19]. The common type of ball and beam system usually comprises a mechanical combination of motor, gear and pull belt. It also uses the servo motor as an actuator to control the angle of the beam. With this proposed system, pneumatic-servo cylinder is used as an actuator to control the angle of the beam and it will give more challenging in control system. Therefore, a good control algorithm is important in determined the performance of the proposed system.

1.4 Objective

The main objective of this research is to develop a position controller for pneumatic-servo cylinder to give better position of the pneumatic stroke. In order to achieve the objective, several sub-objectives are outlined below

The sub-objectives of the research are:

I. To design a position controller using fuzzy-based controller for the pneumatic-servo cylinder.
II. To tune the parameter (scaling factors) available in the controller design using Particle Swarm Optimization (PSO) technique.
III. To do simulation analysis and then to validate it with real-time experiment through MATLAB/Simulink using Data Acquisition (DAQ) card.
IV. To propose and develop a Pneumatic Actuated Ball and Beam System (applying the position controller).

1.5 Scope

This research intends to concentrate on several scopes such as listed below:

I. Designing a fuzzy-based controller based on previous transfer function model of the pneumatic-servo cylinder using MATLAB/Simulink for simulation evaluation.

II. The parameters that have to be optimized are the scaling factors available in the controller design.

III. Validating the designed controller with real-time experiment for position control and tested with external load for robustness and performance checking using NI PCI/PXI 6221 DAQ card as a communication tool.

IV. Developing Pneumatic Actuated Ball and Beam System by using two servo-pneumatic actuators (one fixed and the other one moving).

1.6 Thesis Outline

Chapter 1 provides a brief introduction of pneumatic actuator and its background. The objectives and the problem statement of the research were also stated. The areas that the project will be focused on were explained in the scope of research.

Chapter 2 provides a literature review in the area of the pneumatic actuator. Types of the pneumatic actuator, the position controls algorithm, optimization technique and the application of the pneumatic actuator are discussed in detail. The summary of all the literature reviews are also included in this chapter.

Chapter 3 describes the methodology used throughout the research. This covers the system designs and models, the controller designs, optimization technique that have been used and the experiment setups done. The controller simulation and experimental analysis were performed using MATLAB/Simulink.

Chapter 4 explains the details of the design of the Pneumatic Actuated Ball and Beam System (PABBS) structure. The CAD design of the system was designed using SolidWorks software. The overall dimension of the structure is provided in this chapter.

Chapter 5 discusses the implementation of the controller designs and the proposed application. The simulated results are obtained and compared with real-time experiments. An analysis of the results is made and compared with other types of controller.

Chapter 6 discusses the conclusion of the research and future work that can be done to improve the research project.

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