# SYSTEM IDENTIFICATION AND POSITION CONTROL OF PNEUMATIC ACTUATOR USING EMBEDDED SYSTEM

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*Specially dedicated to*
*my parents, my family and my friends for their*
*patience, support, prayers, encouragement and blessings*

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# ABSTRACT

This project report presents the ability of using embedded system to control non-linear systems like pneumatic actuators. The pneumatic actuators are commonly used in industrial applications because they have many practical advantages such as high power to weight ratio and cheap compared to other actuators. Embedded system STM32F4DISCOVERY was used in this project to interface the pneumatic actuator with MATLAB® Simulink instead of using the conventional Data Acquisition card (DAQ) to reduce the cost and size. The embedded system was also used as a controller to execute the control algorithms. The model of the pneumatic actuator was identified by using system identification technique. Based on this model, the Proportional-Integral-Derivative (PID) and the Proportional-Derivative Fuzzy Logic (PD-Fuzzy) controllers were designed to control the position of the pneumatic actuator. Waijung Blockset in MATLAB® Simulink was used to estimate the model of the pneumatic actuator and implement these controllers inside the embedded system STM32F4DISCOVERY. A Pneumatic Actuated Ball and Beam System (PABBS) is an application of controlling the position of the pneumatic actuator. The developed model of PABBS was used to design three controllers for this plant based on the controllers of the pneumatic actuator. The Cascade PID, the PD-Fuzzy with Gain Feedback and the PD-Fuzzy with PID controllers were designed to control the ball at the desired position. For the position control of the pneumatic actuators, the simulation and experimental results of the PID and PD-Fuzzy controllers were presented. The PD-Fuzzy offers better control compared to other controllers in terms of stability and robustness for the pneumatic actuator. On the other hand, PD-Fuzzy with PID controllers gave the best control response in the simulation compared to the others controllers for the PABBS application.

# ABSTRAK

Tesis ini membentangkan keupayaan menggunakan sistem terbenam untuk mengawal sistem tidak linear seperti penggerak pneumatik. Penggerak pneumatik biasanya digunakan dalam aplikasi industri kerana ia mempunyai banyak kelebihan praktikal seperti nisbah tenaga kepada berat yang tinggi selain murah berbanding dengan penggerak lain. Sistem terbenam STM32F4DISCOVERY telah digunakan dalam projek ini untuk menghubungkan penggerak pneumatik dengan MATLAB® Simulink disebalik menggunakan DAQ konvensional (Data kad Perolehan) untuk mengurangkan kos dan saiz. Sistem tertanam juga digunakan sebagai pengawal untuk melaksanakan algoritma kawalan. Model penggerak pneumatik telah dikenal pasti dengan menggunakan teknik Pengenalpastian Sistem (SI). Berdasarkan model ini, pengawal PID dan PD-Fuzzy telah direka untuk mengawal kedudukan penggerak pneumatik. Waijung Blockset dalam MATLAB® Simulink telah digunakan untuk menganggar model penggerak pneumatik dan melaksanakan pengawal ini di dalam sistem STM32F4DISCOVERY terbenam. Sistem bebola dan palang pneumatic (PABBS) adalah sebuah aplikasi bertujuan mengawal kedudukan penggerak pneumatik. Model yang dibangunkan daripada PABBS telah digunakan untuk mereka bentuk tiga pengawal untuk pelan ini berdasarkan pengawal penggerak pneumatik. PID lata, PD-Fuzzy dengan maklumbalas dan PD-Fuzzy dengan pengawal PID yang telah direka untuk mengawal bola pada kedudukan yang dikehendaki. Bagi kawalan kedudukan daripada penggerak pneumatik, simulasi dan keputusan eksperimen daripada PID dan pengawal PD-Fuzzy telah dibentangkan. Kawalan PD-Fuzzy adalah lebih baik berbanding dengan pengawal lain dari segi kestabilan dan kemantapan untuk penggerak pneumatik. Sebaliknya, PD-Fuzzy dengan pengawal PID memberi tindak balas kawalan terbaik dalam simulasi berbanding dengan yang pengawal lain untuk aplikasi PABBS.

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| | | |
|---|---|---|
| ARX | - | Auto-Regressive with Exogenous |
| ARMAX | - | Auto-Regressive Moving Average with Exogenous |
| DAQ | - | Data Acquisition |
| FIS | - | Fuzzy Inference System |
| FLC | - | Fuzzy Logic Control |
| I/O | - | Input/ Output |
| MF | - | Membership Function |
| PABBS | - | Pneumatic Actuated Ball and Beam System |
| PD | - | Proportional-Derivative |
| PI | - | Proportional-Integral |
| PID | - | Proportional-Integral-Derivative |
| PWM | - | Pulse Width Modulation |
| SI | - | System Identification |
| SISO | - | Single Input Single Output |
| TF | - | Transfer Function |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Pneumatic actuators are often used to convert the energy of compressed air into mechanical energy. They are widely used in robotics, medical applications and automation applications because they offer many useful advantages. Also, electric motors are used as actuators in various applications like robotics and automation applications because they are easy to control and interface precisely. But, electrical actuators have several disadvantages such as low power to weight ratio, high current related with its load and heavy. The hydraulic actuators are not ecological, need hydraulic oil and their pumps need return lines. On the other hand, the pneumatic actuators are clean, economy, light, fast, have a great power to weight ratio and do not need return lines. However, the pneumatic actuators have highly nonlinear characteristics due to the air compressibility behavior and internal friction. Because of these conditions, there are certain difficulties in pneumatics cylinder control design [1]. One of these difficulties is the usage of pneumatic actuators cannot be controlled precisely. Furthermore, pneumatic actuators have nonlinear, high-order dynamics and parametric uncertainties due to friction and air compressibility [2].

Ball and beam system is one of the most common laboratory systems and it is classified under tracking control. This prototype is used for education purposes and experimental verifications of applied control algorithms. This system depends on controlling the position of a ball rolling on the top of a long beam by adjusting the angle of the beam. The dynamics of this system are complex and unstable open loop system. There are many prototypes of ball and beam system that use D.C motor to control the angle of the beam. Recently, the researchers have been trying to design and build a new prototype of ball and beam system that uses pneumatic actuator to control the angle of the beam. This prototype has many non-linear characteristics that cause difficulties in controlling this system. Figure 1.1 represents the common actuators that use in ball and beam system.

Embedded systems are a new technique that came with the revolution of technology and can be seen everywhere in our life. An embedded system is a special-purpose computer system designed to perform some decided functions. IEE defines the embedded system as a device used to control, monitor or assist the operation of equipment, machinery or plant [3]. The embedded system consists of microprocessor, RAM, ROM, and I/O peripheral. All computing systems have constraints on design metrics unlike those in embedded system. A design metric is a measure of an implementation's features, such as cost, size, performance, and power. Embedded systems are cheap, have small size, fixed in one chip, active suitable performance to process data in real-time, and have low power consumption.

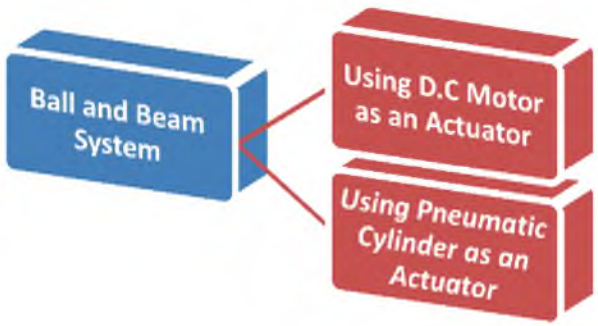


**Figure 1.1** Types of Ball and beam system

## 1.2 Problem Statement

Due to the several advantages of pneumatic actuators, they are used in many applications. On the other hand, it is difficult to control the position of pneumatic actuator because of its non-linear characteristics. The prototype of the Pneumatic Actuated Ball and Beam System (PABBS) is a new application of controlling the position of the pneumatic actuator as in [4]. The significance of this prototype is due to the challenge of controlling the position of the ball along the beam by controlling the beam angle. In PABBS, the sensors and the actuators are interfaced with computer via National Instrumentation Data Acquisition card (NI-DAQ), to control the system in real-time using MATLAB® Simulink blocks. The designer uses the personal computer to apply the control algorithm via the interface between the computer and the system, which leads to more power consumption and cost. In addition, the big size of personal computer causes another drawback.

## 1.3 Research Objectives

- To develop the model of Pneumatic Actuator by using System Identification (SI) technique.
- To design PID and PD-Fuzzy controllers for controlling the position of Pneumatic Actuator in MATLAB® and implement them inside embedded system (STM32F4DISCOVERY).
- To design three different controllers to control Ball and Beam system in MATLAB® Simulink.

## 1.4 Scope of Work

- Use system identification to estimate the linear position model of Pneumatic Actuator and use this model to design PID and PD-Fuzzy controllers to control the position of the pneumatic actuator.
- Implement the PID and PD-Fuzzy controllers inside the flash memory of the embedded system (STM32F4DISCOVERY) board.
- Build the Cascade model of Pneumatic Actuated Ball and Beam system and design the controllers for this system based on the position controllers of the pneumatic actuator by using MATLAB® Simulink blocks.
- The interfaced with MATLAB® Simulink in real-time just to measure the response.

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