

OBSERVER-BASED RECEDING HORIZON CONTROLLER FOR POSITION  
AND FORCE CONTROL OF A PNEUMATIC ACTUATOR

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## ABSTRACT

Pneumatic systems are widely used in automation industries and in the field of automatic control. Unfortunately, some nonlinearities are existed in these actuators. These nonlinearities have made controlling these actuators more difficult to get good dynamic performance. In this project, Receding horizon controller (RHC) is proposed to control the position and the force of a pneumatic actuator. RHC is a predictive controller that predicts the future output and decides the acting signal to reduce the future errors. The type of RHC used in this project is a state feedback controller. Three types of pole assignment observers are used in this project in order to estimate the states of the position and the force models. The observers are designed, incorporated with RHC and then compared in terms of their estimation errors. The implementations of RHC and the observers are carried out using MATLAB/Simulink. Using a data acquisition system (DAQ) real time control between the computer and the pneumatic actuator is established. The RHC shows good control performance both in controlling the position and the force. The experimental and the simulation results of RHC are compared to validate the controller. To further evaluate the RHC controller, its results are compared with other controllers done in previous works, and it is found that RHC has some advantages over these controllers in terms of the control performance criteria.

## ABSTRAK

Sistem pneumatik digunakan secara meluas dalam industri automasi dan dalam bidang kawalan automatik. Malangnya, wujud keadaan tidak linear dalam aktuator terbabit. Keadaan tidak linear ini telah menyebabkan kawalan terhadap aktuator lebih sukar untuk mendapatkan kawalan dinamik yang lebih baik. Dalam projek ini, *Receding Horizon Controller* (RHC) dicadangkan untuk mengawal posisi (*position*) dan daya (*force*) penggerak pneumatik. RHC adalah pengawal ramalan yang meramalkan output akan datang dan memutuskan isyarat yang bertindak untuk mengurangkan kesilapan-kesilapan akan datang. Jenis-jenis RHC digunakan dalam projek ini adalah keadaan pengawal suap balik (*feedback controller*). Tiga jenis pemerhati tugas kutub (*pole-assignment observers*) telah digunakan dalam projek ini untuk menganggarkan keadaan-keadaan mengenai posisi dan model daya. Pemerhati direka, digabungkan dengan RHC dan kemudian dibandingkan dari segi kesilapan anggaran mereka. Pelaksanaan RHC dan pemerhati dijalankan menggunakan MATLAB / Simulink. Dengan menggunakan Sistem Perolehan Data (DAQ) kawalan masa sebenar (*real time*) di antara komputer dan penggerak pneumatik telah dihasilkan. RHC telah menunjukkan prestasi kawalan yang baik dalam mengawal bagi kedua-dua posisi dan daya. Eksperimen dan keputusan simulasi RHC kemudiannya dibandingkan untuk mengesahkan kemampuan pengawal. Untuk menilai selanjutnya pengawal RHC, keputusan yang dibandingkan dengan pengawal lain yang dilakukan dalam kerja-kerja sebelum ini, dan didapati bahawa RHC mempunyai beberapa kelebihan berbanding pengawal lain dari segi beberapa kriteria prestasi kawalan.

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**LIST OF ABBREVIATIONS**

ARMAX	-	Auto-Regressive Moving Average with Exogenous
ARX	-	Auto-Regressive with Exogenous
CCF	-	Controllable Canonical Form
DRNN	-	Diagonal Recurrent Neural Network
IPA	-	Intelligent Pneumatic Actuator
MPC	-	Model Predictive Control\Controller
OCF	-	Observable Canonical Form
PI	-	Proportional-Integral
PID	-	Proportional-Integral-Derivative
PWM	-	Pulse Width Modulation
RHC	-	Receding Horizon Control
SI	-	System Identification

## CHAPTER 1

### INTRODUCTION

#### 1.1 An Overview on Pneumatic Actuators

Pneumatic actuators are widely used in a variety of automation industries. If they are given precision tracking ability in addition to their relatively small size, light weight and high speed, they can be used for many robotic and medical applications.

Moreover, pneumatic actuators are safe and reliable. They have relatively small size compared to hydraulic actuators. Moreover, they have fast response, and at high temperatures and in nuclear environments, they have the advantages over hydraulic actuators because gases are not subjected to the temperature limitations (Ali *et al.*, 2009).

These merits, and more others, of pneumatic systems have motivated many researchers among the years to propose different approaches of controllers to get better accuracy and better dynamic performance. Their main interest is to control the position, but due to different industry and automation requirements, their interests had extended to control the force, stiffness and viscosity of the pneumatic actuators.

The difficulties of controlling pneumatic actuators are mostly because of the nonlinearities existed. The high frictional forces that the pneumatic actuator is

subjected to, the compressibility of air, the valve dead zone, etc are all sources of the nonlinearities. As a result, these nonlinearities made it difficult to achieve accurate position control of the pneumatic actuators.

There are mainly two types of pneumatic actuators, the piston-cylinder type, which is the most popular and existed one, and the rotary type. Based on the historical development, pneumatic systems were created since the 16th century (Ahmad *et al.*, 2012). Since then, many development has been done to the pneumatic actuators to suit different automation and industry purposes according to the desired accuracy and performance and to the amount of force that is needed to each particular application. In the 20 century, more complex and intelligent pneumatic systems were developed. The Intelligent pneumatic actuator (IPA) system, which is dealt with in this study, is referred from Faudzi *et al.*, where A. A. M. Faudzi developed intelligent actuators and applied them to Pneumatic Actuator Seating System (PASS) as an application.

## **1.2 Problem Statement**

There are difficulties in controlling the position and force of pneumatic actuators due to the nonlinearities existed.

More work regarding the position and force control is needed to achieve higher accuracy and better dynamic performance.

## **1.3 Project Objectives**

The objectives of this project are:

- 1) To design and implement a receding horizon controller based on the discrete-time model of a pneumatic actuator to simulate position and force control.
- 2) To design a discrete-time observer to estimate the states.
- 3) To conduct real time control with the pneumatic actuator.
- 4) To validate the results with the experimental data and with a different controllers.

#### **1.4 Scope of Work**

The mathematical models of position and force are previously developed by Ahmad *et al.*, (2012) and Elnimair, (2013) respectively. Using these models, Receding Horizon Controller (RHC) is studied, designed, tuned and implemented using MATLAB/Simulink. Three types of observers are designed (to estimate the states) and implemented using MATLAB/Simulink also. The position and force control are simulated. Thereafter, using data acquisition (DAQ) system real time control is conducted with the pneumatic plant for performance testing

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