FORCE CONTROL USING PREDICTIVE FUNCTIONAL CONTROL (PFC) ALGORITHM FOR TWO CHAMBERS SOFT ACTUATOR

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Masters of Engineering (Electrical-Mechatronics & Automatic Control)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JUNE 2014

This project is dedicated to my beloved mother Haj. Nafisa Habib, father Alh. Kabir.M. Dankadai, my brothers my sisters and Rabi’u Kwankwaso for their encouragement and blessing, support and caring.

ACKNOWLEDGEMENT

In The Name of God.

I am particularly grateful to ALLAH (S.W.T.) for giving me the courage, strength and ability to successfully undertake and complete this report work.

I would like to express my gratitude to my project supervisor, Dr. Ahmad Athif Mohd Faudzi for his moral support, making useful corrections, comments, suggestions to improve the quality of this project and took the pains in reading the entire thesis scripts.

I am indebted to express my thanks to my friends Amiru Bature, Usman Tasi'u, Shahrul Hamzah bin Abdul Razak, Khairuddin Osman and Muhammad Rusydi and also the entire staffs of Electrical Engineering Department.

Finally I would like to dedicate this achievement to my parents, family and friends who have helped me directly or indirectly and sacrificed a lot in the completion of this study.

ABSTRACT

The current trend in the world of automation and robotics heavily applies metal structure type of the actuators which are heavy, rigid, difficult and expensive to develop. Other areas of applications like medical, agriculture, biological and welfare requires less rigid and safer robots. Thus, a biologically inspired robot is required to meet this certain criteria. This lead to the recent attraction in the study and development of Pneumatic Soft Actuator (PSA) because it has more advantages over hard actuators to suit the applications mentioned above due to its simple structure, low cost, high efficiency, high compliance, high power to weight ratio and ensures safe and more natural way of interaction. Despite the advantages of pneumatic soft actuator it has nonlinearity and hysteresis, which makes them difficult to model and control. The main objective of this study was to obtain mathematical model and control the force of a two chamber pneumatic soft actuator. Obtaining nonlinear mathematical model accurately to be used in controller design needs to determine all physical parameters of the real system which is very expensive and time consuming, to simplifying this procedure, model of system was analysed and obtained using system identification toolbox in MATLAB software. Input and output data was acquired from an experimental setup which was used to obtain a transfer function force model of the system. The best model was accepted based on the best fit criterion through SI toolbox. Predictive Functional Controller (PFC) was designed and simulated for the model via MATLAB/Simulink. The results showed that PFC controller provides better output than a conventional PID controller when tested using several references. PFC controller exhibits faster response to the system with desired transient error. The study represented in this project can be further broaden by taken position control into account and validation of the simulated control can be done on the experimental setup.

ABSTRAK

Trend semasa di dalam dunia automasi dan robotik banyak bergantung kepada jenis penggerak dari struktur logam yang berat, tegar, mahal dan sukar untuk dibangunkan. Antara bidang lain yang menggunakan aplikasi ini adalah seperti perubatan, pertanian, biologi dan kebajikan yang memerlukan robot yang kurang tegar dan lebih selamat. Oleh itu, sebuah robot yang berinspirasikan biologi diperlukan untuk memenuhi kriteria yang tertentu. Hal ini membawa kepada tarikan terbaru dalam kajian dan pembangunan penggerak pneumatik lembut kerana ia mempunyai banyak kebaikan berbanding penggerak kasar untuk disesuaikan dengan aplikasi yang disebutkan di atas kerana ia mempunyai struktur yang mudah, kos rendah, kecekapan tinggi, pematuhan yang tinggi, kuasa tinggi kepada nisbah berat dan menjamin keselamatan serta interaksi yang lebih semula jadi. Walaupun penggerak pneumatik lembut mempunyai pelbagai kebaikan, namun sifatnya yang tidak linear dan histerisis, menjadikan ianya sukar untuk dimodel dan dikawal. Objektif utama kajian ini adalah untuk mendapatkan model matematik dan mengawal daya pada sebuah penggerak pneumatik lembut yang mempunyai dua kebuk. Data bagi masukan dan keluaran diperolehi daripada eksperimen yang dijalankan dan ianya digunakan untuk medapatkan model persamaan daya bagi sistem ini. Model terbaik yang diterima adalah berdasarkan kepada kriteria sesuai yang terbaik melalui kelengkapan pengenalan sistem (SI Toolbox). Pengawal fungsi ramalan (PFC) telah direkabentuk dan model telah disimulasikan dengan menggunakan perisian MATLAB/SIMULINK. Hasil kajian menunjukkan pengawal PFC mampu menyediakan keluaran yang lebih baik berbanding pengawal PID konvensional apabila diuji dengan beberapa rujukan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AI	- Artificial Intelligence
ARX	- Auto-Regressive with Exogenous
ARMAX	- Auto-Regressive Moving Average with Exogenous
BJ	- Box-Jenkins
DC	- Direct Current
FIS	- Fuzzy Inference System
GA	- Genetic Algorithms
GD	- Gradient Descent
ID	- Identification
LMS	- Least Mean-Squares
MGA	- Modified Genetic Algorithm
MPC	- Model Predictive Control
NN	- Neural Network
N-PID	- Nonlinear Proportional Integral Derivative
NARX	- Nonlinear Auto-Regressive with Exogenous
OE	- Output Error
PAM	- Pneumatic Artificial Muscle
PFC	- Predictive Functional Controller
PI	- Proportional – Integral
PD	- Proportional - Derivative
PID	- Proportional Integral Derivative
PSA	- Pneumatic Soft Actuators
PSO	- Particle Swarm Optimization
SI	- System Identification

CHAPTER 1

INTRODUCTION

1.1 Project background

In the use of pneumatic system is rapidly increasing in the sector of automation and modern industry. Therefore nowadays a lot of pneumatic actuation tools are being developed, studied and used in order to convert compressed gas energy to mechanical energy [1]. Some of the pneumatic actuators used include tie rod cylinders, rotary actuators, grippers, rodless actuators with magnetic linkage or rotary cylinders, Rodless actuators with mechanical linkage, pneumatic artificial muscle and Vacuum generators e.t.c. The current trend in the world of automation and robotics heavily applies metal structure type of the actuators which is heavy rigid difficult and expensive to develop and not suitable for human interaction. Other areas of applications like medical, agriculture, biological and welfare requires less rigid and safer robots. A biologically inspired is required to meet this criterion in order to perform tasks with more safety. This leads to the recent attraction in the study and development of pneumatic artificial muscle (soft actuator). This type of soft actuator has its own advantages over the hard type. Table 1.1 shows some of the qualifications.

A 2- chambers pneumatic soft actuator will be considered in this project. A 2- chambers Soft pneumatic Actuator is made of rubber with fiber reinforce and has a cylindrical shape with two symmetrical holes (chambers) as shown in Figure 1.1.

It can deform in three motions of shorten, elongate and bend. It uses only pneumatic input to move and having a soft motion in its movements.

Table 1.1: Advantages of soft actuators over hard actuators**.**

PROPERTIES	SOFT ACTUATOR	HARD ACTUATOR
Safety	Safe	Dangerous
Working Environment	Structured and unstructured	Structure only
Degree of freedom/compliance	Infinite	Few
Cost	Low	High
Robotic actuation	Under Actuated	Fully actuated

Due to the soft actuator type of applications, the need for a robust, flexible and precise control of soft actuator is required. Soft actuators are difficult to control using classical control because they have nonlinearity; hysteresis and their behavior also change with time. In addition to that soft actuators are also difficult to obtain accurate and parsimonious model that adequately describe the behavior of the system [1]

Many methods which are categorized as analytical modeling, numerical Modeling and artificial Intelligence based modeling [2] has been used to build dynamic equations that best represent the soft actuator. One of the most popular and effective way is to chose a given model structure based on the prior knowledge of the system and identify the system parameters by estimation method using experimentally acquired data. This method is known as System ID method

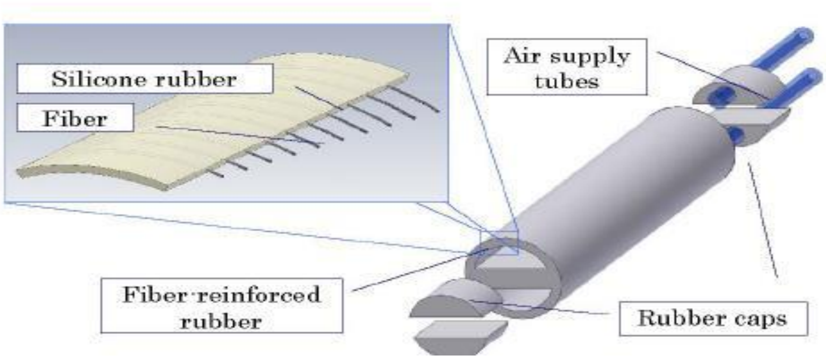

Figure 1.1 A two chamber pneumatic soft actuator [27].

Based on all that mentioned before, it can be learnt that pneumatics soft actuator are a qualified alternative over pneumatic hard actuator systems if there is a solution to tackle its problems. Thus, controller design and its implementation for pneumatic soft actuators is one of the challenging problems in control engineering.

Predictive Functional Control (PFC) design is selected as the control strategy for the pneumatic system. Performance assessment of the PFC controller is performed in MATLAB. Result shows that the PFC controller is adapted to the system and able to control successfully in the simulation.

1.2 Problem statement

Due to its type of applications, the need for a robust, flexible and more accurate force control arises.

Soft actuators are difficult to control using classical control because they have:

i. nonlinearity.

ii. hysteresis .
iii. it’s behavior also varies with time.

Difficult to obtain accurate and parsimonious model that adequately describe the behavior of the system

1.3 Project Objectives

The objective of this project is to precisely control the bending force exerted by the two chamber pneumatic soft actuator with an accurate and fast enough response are desired. So regarding to this aim, overall objective can be divided into three. Which are**:**

To develop a force mathematical model of a 2- chambers pneumatic soft actuator.

i. To design a controller using Predictive functional control for a soft actuator flexible mechanism.
ii. To simulate and analyze the characteristics of the force control in MATLAB/simulink software.

1.4 Project scope

The scope of work in fulfilling the project objectives are;

i. A two chamber pneumatic soft actuator will be considered.
ii. The mathematical model of force for the two chamber pneumatic soft actuator will be obtained by implementing system identification method.

iii. Predictive functional control will be studied, designed, tuned and implemented using MATLAB /simulink.

iv. Also, the force control will be simulated using MATLAB/Simulink.

1.5 Project Report Outline

This project thesis is organized in five chapters. Chapter one gives an overview of the system, objectives and scope of the project and also gives introduction regarding the problem to be solved. Chapter two reviews some previous research and literatures related to this project. Chapter three provides steps of the methodology and description of each procedure to be followed in order to solve the problem at in view. Chapter four gives a detailed explanation of the results obtained from simulation and experiment and discuses the outcomes from the followed methodology. And finally chapter five presents conclusion on the achievements in the project and also set forth some recommendations for further future works.

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