Faculty of Electrical Engineering

ENHANCED-PID CONTROL OF ANTAGONISTIC PNEUMATIC ARTIFICIAL ACTUATED SYSTEM

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Master of Science in Mechatronics Engineering

2016

ENHANCED-PID CONTROL BASED ANTAGONISTIC CONTROL FOR PNEUMATIC ARTIFICIAL MUSCLE ACTUATORS

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITY TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this thesis entitled "Enhanced-PID Control of Antagonistic Pneumatic Artificial Actuated System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechatronics Engineering.

Signature	:	…………………………….............................
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DEDICATION

To my beloved father, mother and sisters.

ABSTRACT

Pneumatic artificial muscle (PAM) is a rubber tube clothed with a sleeve made of twisted fiber-code, and is fixed at both ends by fixture. It has a property like a spring, which enables it to change its own compliance by the inner air pressure. The advantages of pneumatic system such as high power-to-weight ratio, compactness, ease of maintenance, inherent safety and cleanliness led to the development of McKibben muscle and PAM actuators. However, the drawbacks of PAM, for example, the air compressibility and the lack of damping ability of PAM bring dynamic delay to the pressure response and cause oscillatory motion to occur. It is not easy to realize the PAM motion with high accuracy and high speed due to all the non-linear characteristics of pneumatic mechanism. In this thesis, an antagonistic-based PAM system is designed and presented. Two identical PAM actuators are connected in parallel and vertical direction which imitate the human biceps-triceps system and emphasize the analogy between the artificial muscle and human skeletal muscle behavior. Some past control algorithms on the positioning control of PAM mechanisms are discussed. In this thesis, a practical control method, namely enhanced-PID controller is proposed to control the trajectory motion of the PAM actuators. The development and modeling of the experiment setup are explained, followed by the driving characteristics of the PAM system. Two simple and straight forward steps are demonstrated as the design procedures of the enhanced-PID controller. The control structure of the proposed controller consists of a PID element, Compensator A and Compensator B. The effectiveness of the proposed control algorithm is validated in sinusoidal continuous motion. The tracking performance of the enhanced-PID controller is compared with a classic PID controller, showing that the control performance of the enhanced-PID controller is satisfactory and better in dealing with highly non-linear PAM system.

ABSTRAK

Otot tiruan pneumatik (PAM) merupakan sejenis tiub getah dengan lengan yang diperbuat daripada kod serat, dan ditetapkan pada kedua-dua perlawanan hujung. Ia mempunyai ciri seperti spring, yang membolehkannya menukar pematuhan sendiri dengan tekanan udara dalaman. Kelebihan sistem pneumatik seperti kuasa tinggi kepada nisbah berat badan, kompak, kemudahan penyelenggaraan, keselamatan dan kebersihan yang wujud membawa kepada pembangunan otot McKibben dan penggerak PAM. Walau bagaimanapun, kelemahan PAM, sebagai contohnya kebolehmampatan udara dan kekurangan redaman keupayaan PAM membawa kelewatan dinamik kepada tindak balas tekanan angin dan seterusnya menyebabkan gerakan ayunan berlaku. Memang adalah tidak mudah untuk merealisasikan gerakan PAM dengan ketepatan dan kelajuan yang tinggi disebabkan oleh semua ciri-ciri bukan linear mekanisme pneumatik. Dalam tesis ini, sistem PAM yang bertentangan telah direka dan dibentangkan. Dua batang penggerak PAM yang sama disambungkan dalam arah selari dan tegak supaya meniru sistem bisep-trisep manusia serta menekankan analogi antara otot tiruan dan tingkah laku otot rangka manusia. Beberapa algoritma kawalan lama yang menekankan kawalan kedudukan mekanisme PAM telah dibincangkan. Dalam tesis ini, satu kaedah kawalan yang praktikal, iaitu pengawal peningkatan PID telah dicadangkan untuk mengawal gerakan trajektori dari penggerak PAM. Pembangunan dan pemodelan persediaan eksperimen telahpun diterangkan, diikuti oleh ciri-ciri memandu sistem PAM. Sebanyak dua langkah mudah sahaja yang diperlukan telah ditunjukkan sebagai prosedur reka bentuk pengawal peningkatan PID. Struktur kawalan pengawal yang dicadangkan terdiri daripada elemen PID, pemampas A dan pemampas B. Keberkesanan algoritma kawalan yang dicadangkan tersebut disahkan dalam eksperimen berasaskan gerakan berterusan sinusoidal. Prestasi pengesanan pengawal peningkatan PID telah dibandingkan dengan pengawal PID klasik, menunjukkan bahawa prestasi kawalan pengawal peningkatan PID adalah memuaskan dan lebih baik dalam menangani sistem PAM yang tidak linear.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor, Dr. Chong Shin Horng from the Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for her essential supervision, support and encouragement towards the completion of this thesis.

I would also like to express my greatest gratitude to Dr. Ahmad Zaki bin Shukor from Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), co-supervisor of this research for his advice and suggestions. Particularly, I would like to express my deepest gratitude to all lab members from Motion Control Research Lab (MCRL) for their assistant and efforts in all the lab and analysis works.

Special thanks to Zamalah scholarship, Universiti Teknikal Malaysia Melaka (UTeM) for the financial support throughout this project.

Last but not least, I would like to thank my family and friends for their moral support in completing this degree. Thank you to everyone who had been associated to the crucial parts of realization of this project.

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LIST OF ABBREVIATIONS

ABBREVIATION		DETAIL
ADC	-	Analogue to digital converter
AN-PID	-	Advanced Nonlinear Proportional-Integral-Derivative
ARC	-	Adaptive Robust Control
DAC	-	Digital to analogue converter
DAQ	-	Data acquisition unit
DOB	-	Disturbance Observer
DOF	-	Degree-of-freedom
DSC	-	Dynamic Surface Control
GA	-	Genetic Algorithm
GPIO	-	General-purpose input/output
I/O	-	Input/Output
ISAC	-	Intelligent Soft Arm Control
IPPSC	-	Intelligent Phase Plane Switching Control
LMS	-	Least Mean Square
LSE	-	Least Square Error
LVQNN	-	Learning Vector Quantization Neural Network
MGA	-	Modified Genetic Algorithm
MRB	-	Magneto-Rheological Brake
MRLS	-	Modified Recursive Least Square

MVC	-	Minimum Variance Control
NARX	-	Non-linear Autoregressive with Exogenous input
NDOBC	-	Non-linear Disturbance Observer Based Control
NDOBDSC	-	Non-linear Disturbance Observer Based Dynamic Surface Control
PAM	-	Pneumatic Artificial Muscle
PC	-	Personal computer
PD	-	Proportional-Derivative
PID	-	Proportional-Integral-Derivative
PMA	-	Pneumatic Muscle Actuator
PPSC	-	Phase Plane Switching Control
SMC	-	Sliding Mode Control
SMCBNDO	-	Sliding Mode Control Based on Non-linear Disturbance Observer
SOM	-	Self-organizing Map
T-S	-	Takagi-Sugeno

LIST OF SYMBOLS

SYMBOL		DETAIL
a	-	Amount of inflation
a_0	-	Initial braided angle
b	-	Amount if deflation
B_1	-	Damping coefficient for PMA 1
B_2	-	Damping coefficient for PMA 2
D	-	Depth
D_0	-	Initial muscle diameter
ε	-	Length ratio of muscle
e	-	Error
E_{max}	-	Maximum peak error
$E_{percent}$	-	Percentage of error
E_{rms}	-	Root mean square of error
f	-	Frequency
H	-	Height
J	-	Moment of inertia
K_1	-	Spring coefficient for PMA 1
K_2	-	Spring coefficient for PMA 2
K_d	-	Derivative gain
K_i	-	Integral gain

K_p	-	Proportional gain
K_u	-	Ultimate gain
L_0	-	Initial muscle length
P	-	Input pressure
P_0	-	Nominal constant pressure
P_u	-	Ultimate period
Δp	-	Pressure difference
r	-	Radius
T	-	Rotating torque
T_d	-	Derivative time
Ti	-	Integral time
θ	-	Rotational angle
θ_r	-	Reference input angle
U_A	-	Signal after PID controller
U_B	-	Signal after Compensator A
U	-	Control voltage
W	-	Width

LIST OF PUBLICATIONS

JOURNAL

1. **Tan, M.H.**, Chong, S.H., Tang, T.F., Shukor, A.Z., Sakthivelu, V., Ma, T.C., and Nawawi, M.R.Md., 2016. Tracking Control of Vertical Pneumatic Artificial Muscle System Using PID. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC) – Special Issue in Pioneering Future Innovation Through Green Technology*, to be published.
2. Tang, T.F., Chong, S.H., **Tan, M.H.**, Chan, C.Y., and Sato, K., 2016. Characterization of Pneumatic Artificial Muscle System in an Opposing Pair Configuration. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC) – Special Issue in Pioneering Future Innovation Through Green Technology*, to be published.
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CONFERENCE

1. **Tan, M.H.**, Chong, S.H., Tang, T.F., Shukor, A.Z., Sakthivelu, V., Ma, T.C., and Nawawi, M.R.Md., 2016. Tracking Control of Vertical Pneumatic Artificial Muscle System Using PID. *The 4th International Conference on Engineering and ICT (ICEI 2016)*.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The human science and technology are getting more advanced as the world is moving forward. Machines and robots are created in order to replace human power. This is because the developed machineries are able to conduct complex work load in a shorter time and more safe condition as compared to the work being carried out by the human being. The motions of machines and robots rely on their own actuation systems as they function in providing forces, torque or any form of mechanical motion to the system in order to move.

There are three major groups of actuators or mechanisms applied to power motion control, such as electric-driven electro-mechanics, hydraulic and pneumatic. Electric system is commonly used as the actuator technology for most of the robotic applications nowadays. The advantages such as easy to use, simplicity, low cost and so on cause electric system to be widely used and applied on actuation system for the machines. However, electric actuator system suffers from the disadvantage of low power-to-weight ratio. Due to the low power-to-weight ratio of electric actuator system as compared to hydraulic and pneumatic systems, some industries prefer to use hydraulic or pneumatic systems as their machine actuator. However, pneumatic system is more preferable than hydraulic system by the industrial. The major advantages of pneumatic systems are their compactness, low cost, east of maintenance, and high power-to-weight ratio characteristic as compared to that of electric and hydraulic system. Therefore, these advantages have led to the development of novel actuator such as McKibben muscle or Pneumatic Artificial Muscle (PAM).

PAM has several advantages over conventional pneumatic cylinders, such as high force-to-weight ratio, flexibilities in installation and lower compressed air. However, difficulties arise when dealing with the modeling controllers for high positioning performance of PAM systems due to their highly nonlinear performance which results from compressibility of the air. As a result, a controller is necessary needed to help in achieving high positioning performance, stability and robustness in the system.

Up to now, various control methods have been designed and evaluated for PAM mechanisms. These proposed control methods can be categorized as classical control, intelligent control and model-based control. The conventional proportional-integral-derivative (PID) control is a classical controller that utilizes model-free control algorithms, including a feedback control action *u(t)* that utilizes the sum of three control parameters. PID controller is still a control approach that widely used in industrial due to its simplicity in structure and design procedure. With the appropriate selection of the three control parameters, the PID control can achieve the desired output and achieve the effectiveness.

In this research, an enhanced-PID controller based antagonistic control for PAM is proposed. The design and constructed PAM mechanism consists of two parallel PAM that provide a rotational antagonistic motion. It is a biologically inspired configuration that commonly applied in a therapy robot and as a breaking system in the industrial area. The effectiveness of the proposed controller is evaluated experimentally in tracking motion with various amplitudes and frequencies.