"I hereby declare that I have read through this report entitled "Development of Control Strategy for Motion Control of Pneumatic Muscle Actuator" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering"

Signature	:	
Supervisor's Name	:	Dr. Chong Shin Horng
Date	:	23.06.2016

DEVELOPMENT OF CONTROL STRATEGY FOR MOTION CONTROL OF PNEUMATIC MUSCLE ACTUATOR

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A report submitted in partial fulfilment of the requirements for the degree

of Bachelors of Mechatronics Engineering

Faculty of Electrical Engineering

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“I declare that this report entitled “Development of Control Strategy for Motion Control of Pneumatic Muscle Actuator” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.”

Signature :

Name : Chan Chun Yuan

Date : 23.06.2016

To my beloved father and mother

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ABSTRACT

Over the past decade, pneumatic muscle actuators (PMA) has been in the limelight and receiving much attention not only in the field of industrial application as well as in prominent research area such as robotics and biomedical engineering. The uprising can be accorded to the many advantages that PMA offers such as inherent complaint safety, low-maintenance and powerful. However, PMA has yet to emerge as disruptors in its application field primarily due to the non-linear dynamics. Despite these detriments, PMA possesses pronounced prospective to be exploited especially in the field of rehabilitation robotics. Henceforth, this research was initiated to propose a control framework taking into account the non-linear dynamics where PMA motion is concerned. A modified Proportional, Integral and Derivative (PID) controller was proposed and the effectiveness of the controller in point-to-point (PTP) positioning motion was evaluated experimentally using a single degree of freedom (1-DOF) PMA system. The modified PID was constructed with the driving characteristics of the PMA system. Subsequently, the positioning performance of the modified PID controller was evaluated and compared with a classical PID controller through experimental means. In general, the proposed modified PID is capable of striking a satisfactory performance in PTP positioning with the reduction of the effect concerning the nonlinearities available in the system.

ABSTRAK

Menelusuri dekad yang lalu, penggerak otot pneumatik semakin mendapat tempat bukan sahaja dalam industri malahan dalam bidang-bidang penyelidikan yang prominen seperti robotik dan kejuruteraan bio-medikal. Populariti ini boleh dikaitkan dengan kelebihan yang ditawarkan oleh penggerak otot seperti ciri-ciri keselamatan, penyelengaraan yang rendah dan kuasa penggerak yang tinggi. Namun, penggerak otot belum dapat mengantikan penggerak yang sedia ada kerana pencirian dinamik tidak linear penggerak sebegini. Akan tetapi, penggerak otot dilihat mempunyai prospek yang tinggi untuk dieksploitasi dalam bidang robotik pemulihan. Oleh itu, kajian ini dimulakan untuk mencadangkan sebuah rangka kerja kawalan mengambil kira dinamik tidak linear yang wujud di mana gerakan penggerak otot dilihat sebagai fokus utama. Untuk menangani isu tersebut, pengawal PID yang telah diubahsuai dicadangkan dan keberkesanan dalam pergerakan titik ke titik terhadap sistem PMA 1-DOF dinilai melalui eksperimen. Pengawal PID yang dicadangkan dibina melalui hubungan antara input dan keluaran yang boleh didapati melalui pencirian gelung terbuka. Penilaian rangka kerja yang dicadangkan dilakukan bersama pengawal PID klasik melalui eksperimen. Secara umumnya, pengawal PID yang telah diubahsuai dapat menunjukkan prestasi yang memuaskan dalam pergerakan titik ke titik bersama dengan keupayaan untuk menolak permasalahan tidak linear.

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LIST OF ABBREVIATIONS & SYMBOLS

DOF	: Degree of Freedom
FLC	: Fuzzy Logic Control
LVDT	: Linear Variable Differential Transformer
PID	: Proportional, Integral and Derivative
PMA	: Pneumatic Muscle Actuator
PPR	: Proportional Pressure Regulator
PT	: Pressure Transducer
PTP	: Point-to-Point

CHAPTER 1

INTRODUCTION

This chapter highpoints the background of the study, problem statement, objectives and the scopes of the project. Background of study is a brief exposition on the system that is being researched and the problem statement dictates the core issue that is to be addressed with this research. Meanwhile, the objectives serve as a benchmark while the scopes define the limits and boundaries of the project in overseeing the project upon completion.

1.1 Background of Study

The emerging technology of robotics in the mid-20th century provides the driving factor for integration of rehabilitation devices with application of robotics. However, the term of rehabilitation robotics was coined in the late 1980 to address the recuperation and rehabilitation of individuals suffering from neurological diseases. Currently, rehabilitation robotics is viewed as one of the few prominent research areas diverged from the main cluster of robotics and linked with the field of biomedical engineering. According to Oxford dictionary, the phrase "rehabilitation" is defined as the action of restoring someone to healthy or normal life through training and therapy after imprisonment, addiction or illness. On the other hand, robotics refers to the division of technology that deals with the design, construction, operation and application of autonomous machines capable of performing a complex series of actions. Hence, rehabilitation robotics can be connoted as a specific scientific field of study associated in discerning and improving rehabilitation with the aid of robotic devices.

Before the application of robotics in rehabilitation devices, the devices are mainly mechanical mechanism that assists patients through physical therapy. Through rehabilitation robots approach, wearable devices such as exoskeleton or prosthesis are implemented. Figure 1.1 shows a brief timeline depicting the development and transition of rehabilitation devices over the decades.

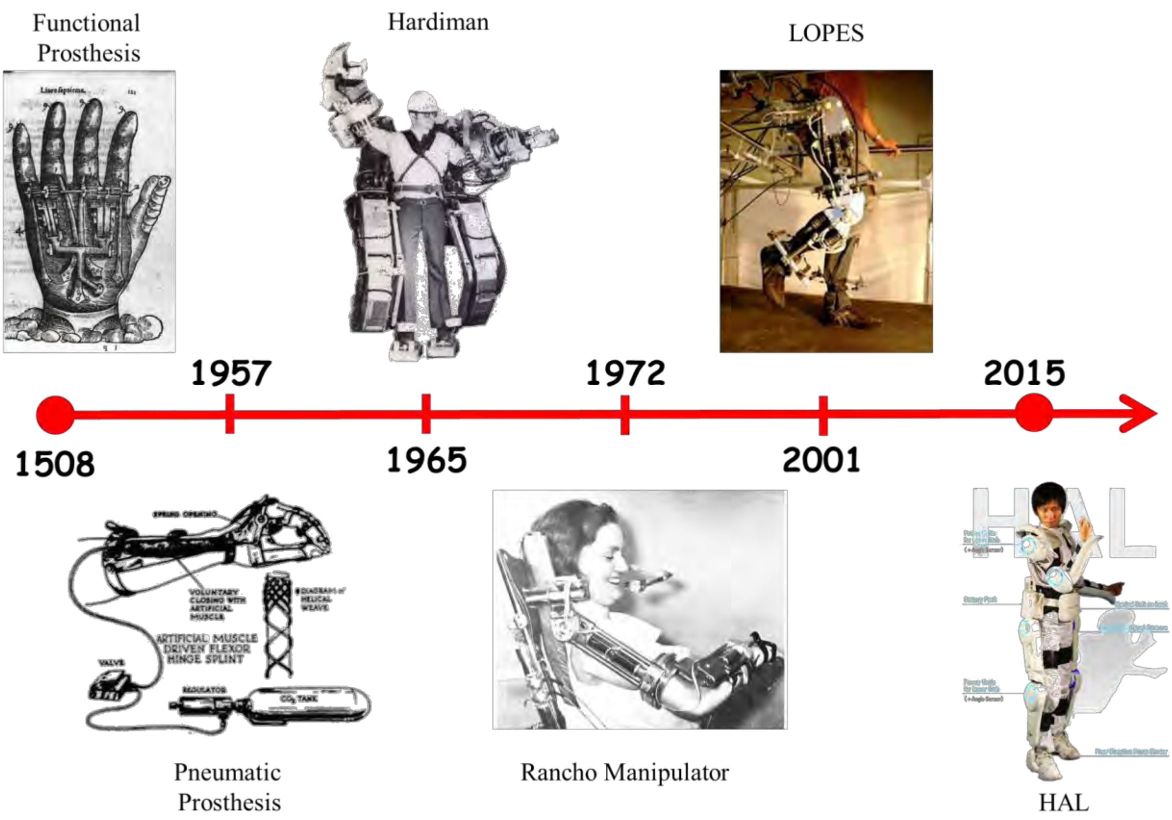

Figure 1.1: Rehabilitation devices development timeline

In the 16th century, the first functional mechanical prosthesis was conceptualised by Ambroise Paré, a royal French barber surgeon in his book of surgery, *Dix Livres de La Chirurgie*. Ambroise came up with the design after performing countless upper limb amputations of wounded French soldiers. The complex prosthesis movement is catered by a series of releases and springs suspended with leather straps. Antoine's design can be viewed as a pioneer of its kind in the development of rehabilitation devices.

In the late 1950s, Joseph Laws McKibben then designed a prosthetic device with the usage of pneumatics actuators. The device served as an orthotic device for polio stricken patients. McKibben invention deemed as a breakthrough as he was the first to implement fluidic actuators in orthotic devices although the fluidic actuators were available before his invention. General Electric developed Hardiman, a powered exoskeleton in mimicry of user locomotion as well as boosting the wearer strength to lift heavy load. However, the attempt was not successful as intense uncontrolled motion was observed with any effort to utilise the exoskeleton.

Rancho Anthropomorphic Manipulator (RAM) was created in 1972 as a joint venture of National Aeronautics and Space Administration with Rancho Los Amigos Hospital. Initially, the orthotic device is created to serve as a tele-operated device that can duplicate human motions in space. Restoration of arm function to paralyzed patients were made possible with RAM. Apart from that, RAM serves as reference model for further development of orthotic rehabilitation robot such as the Wilmington Robotic Exoskeleton (WREX) Arm shown in Figure 1.2.

Figure 1.2: WREX arm with subject usage [1]

Lower Extremity Powered Exo Skeleton (LOPES) [2] is one of the rehabilitation robot that are currently being utilised and researched on by Department of Biomechanical Engineering from University of Twente. LOPES is implemented in gait training in which provide assessment of motor function in the case of stroke survivors. LOPES provides support in leg movements as patients maintain their horizontal balance.

Hybrid Assistive Limb (HAL) is one of the most advanced cyborg type robot concurrently made available by Cyberdyne Inc. HAL is developed with the intention of augmenting and improving human capabilities. Another variation of HAL, the HAL-5 Type- C depicted in Figure 1.3 is utilised as an assistance to paraplegic patient to walk in a standing position. HAL operates as a robotic remedial device that teaches the brain in learning new trajectories.

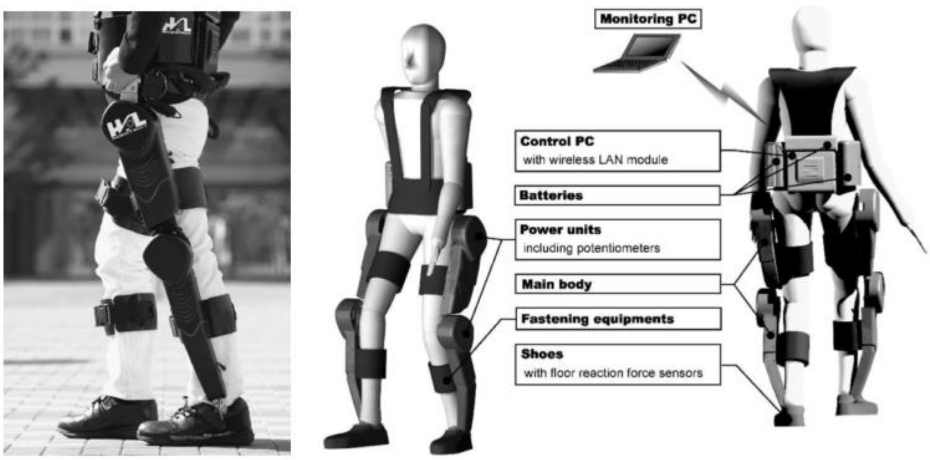

Figure 1.3: HAL-5 type- C

Despite the changes and transition of rehabilitation devices or robots, similar actuation scheme can be observed. Most of the rehabilitation devices or robots utilised electrical actuators in their design. Actuation system embodies an important element in rehabilitation robots design, hence selection of actuation system is made based on these few weightages such as the cost, deliverable power, physical size and responsive rate. Electrical actuators are more preferable as the control for positioning cum velocity is much easier compared to other scheme and its operation is quieter in nature. Despite the extensive usage, electrical actuators are not able to provide a high power/weight ratio in which is a very crucial decisive point in selecting the actuator for the rehabilitation robot.

These lacking provides the motives for constant research in developing new actuators to cater the ever-evolving demands. However, most research outlines technique that involves electrical and hydraulic schemes [3]. Though pneumatic is yet to be exploited in these researches, prospects of pneumatic scheme being utilised is heavily considered. In this research, a pneumatic based driver mechanism was highlighted.

Pneumatic Muscle Actuators (PMA) or Pneumatic Artificial Muscle (PAM) is one of the few pneumatics actuators that are currently being sought after and applied in various fields. Pneumatic muscle actuator is a contractile device manufactured with the inflaTable pneumatic bladder of usually long synthetic or natural neoprene tube wrapped inside artificial mesh at a pre-defined angle [4]. Figure 1.4 shows a variation of PMA namely the fluidic muscle developed by FESTO corporation.

Figure 1.4: FESTO fluidic muscle

The working principle of this actuator is similar to that of an inverse bellow [5]. During pressurisation, the pneumatic bladder expands and as a result from the expansion, the diameter of the mesh and bladder changes in the radial direction promoting shortening of the muscle in the longitudinal direction [6]. Therefore, contraction or pulling force is generated upon inflation of the actuator. When operated, this fluid-driven actuator is capable of providing a striking resemblance to that of muscle-like properties notably the compactness and high power to weight ratio [7]. Apart from that, the operation of PMA can be done with minimal pressurized air consumption indirectly from the small and compact size of PMA alongside with the low costing of implementation and maintenance [8]. Besides, PMA offer a lower level of safety breach in the event of human interactions permitted by its inherent compliant behaviour (Coined as “soft actuator”) in which it is consider safer than electric or hydraulic drives producing the same force level [9]. As a result, an increase in the deployment of this driver mechanism in industrial machinery [10-11], medical applications [12], rehabilitation devices [13-14] and robotics [15-16].

Despite the advantages, there are few disadvantages where the usage of PMA is concerned. These drawbacks explicitly the accuracy and difficulty in control is mainly due to the non-linear characteristics of the actuator itself. Another distinguished shortcoming is related to the sponginess of PMA whereby the positioning of the actuator would be significantly affected by the load variations. Henceforth, these detriments inhibit the exploitation and implementation of the actuators as becoming one of the disruptors in emerging technology such as in droids or humanoid robot’s development. Therefore, this project is conducted with emphasis on the design of control algorithm for point-to-point positioning control of pneumatic muscle actuator.

1.2 Problem Statement

PMA exhibits significant non-linear characteristics in which is attributed to the compressibility of operating medium, intrinsic properties of construction material and the geometric behaviour of PMA external mesh. Since the medium comprised of pressurized air, PMA would be significantly affected by the load variations. The elastic viscous properties of the neoprene tubing and orderly construction of the outer sheath induces different responses under the same conditions of loading as both factors is erratic in nature. The resistance acting inside the interwoven netting also contributes to the non-linear characteristics. Apart from that, PMA also suffers from creep phenomenon caused by the relaxation of the neoprene tubing under pressurization. Besides, hysteresis occurs in PMA as well due to the relative movement within the PMA during inflation or deflation of the muscle. Hence, all of these factors induces dynamic and time-varying behaviours in which makes real time motion control of pneumatic muscle actuator a challenging effort and often inaccurate.

Motivation: - Presently in Malaysia, stroke is one of the major illness that provides the most common cause of severe disability. According to National Stroke Association of Malaysia (NASAM), an estimated 40,000 Malaysians suffer from this illness per annum and anyone has a possibility of having stroke. This number is not inclusive of patients suffering from neurological and other motor-deterioration diseases. This large fraction only applies locally, if this number is projected regionally or globally, an exponential growth in people affected would be observed. Rehabilitation serves to improve patient's motor function and to enable patients to gain as much independence as possible. It is very crucial for patients to acquire the treatment as soon as possible. In view of the current situation, this research aims to provide certain degree of assistance in the research of applicability for PMA in rehabilitation robotics.

1.3 Objectives of Project

This project embarks to achieve the following objectives upon its completion: -

i. To propose and develop a control algorithm for the point-to-point positioning control of 1-Degree of Freedom pneumatic muscle actuator system.
ii. To evaluate the performance of the proposed controller in terms of the point-to-point positioning experimentally.

1.4 Scopes of Project

The main focal point of the research revolves around the positioning control of the 1-DOF pneumatic muscle actuator system. A set of clear and distinct boundaries was defined in order to realise the objectives of this particular research.

i. The pressure operating range of the PMA is well kept between 0 kPa to 450 kPa only.
ii. The environment in which PMA is being operated is maintained at ambient temperature approximately 25^{o} C.
iii. Since the PMA can only contract within 4% of its nominal length (250 mm), the maximum working range is set below 60 mm.
iv. The maximum load tested is maintained below 60 kg.
v. Only the point-to-point positioning performance will be evaluated in this research.

1.5 Thesis Documentation Review

The remainder of this research project is documented and structured as follows. Chapter 2 provides literature write up based on previous research. Chapter 3 highlights the methods undertaken in order to realise the objectives of the research. Preliminary results alongside with the analysis and discussions are offered in Chapter 4. Finally, yet importantly, a conclusion is drawn from the research and emphasised in Chapter 5. Lists of references and appendices pertaining to the research is attached at the end of the document.

CHAPTER 2

LITERATURE REVIEW

This chapter covers the review of previous works pertaining to the current research. Information necessary for the write up of this section was attained from a collection of books, journals, project papers, articles and reference texts.

2.1 Pneumatic Muscle Actuator

Sub-chapter 2.1 is distributed into two parts. Descriptive details of the PMA can be obtained in the first part provided in section 2.1.1. In the next sub-section of 2.1.2, the rudimentary operations principles of PMA are discussed.

2.1.1 Description of Pneumatic Muscle Actuator

Pneumatic muscle actuator (PMA) is a linear driver mechanism derived after the operations of skeletal muscle [17] developed by Joseph L. McKibbens. The invention serves as an orthotic rehabilitative device for polio patients. Due to the limitations where pressure control of pneumatic muscle and a need for a gas reservoir is concerned, pneumatic muscle actuators deployment was stunted. It was until the early 1980s, PMA starts to resurface and being researched on.

Over the years, researchers developed a variety of pneumatic muscle actuators to aid in their research. The different variations of PMA and nomenclatures are provided in the list and in Figure 2.1 below: -

i. Braided Muscle
ii. McKibben Muscle
iii. Netted Muscle
iv. Paynter Hyperboloid Muscle
v. Pleated Pneumatic Artificial Muscle
vi. ROMAC Muscle
vii. Sleeved Bladder Muscle
viii. Yarlott Muscle

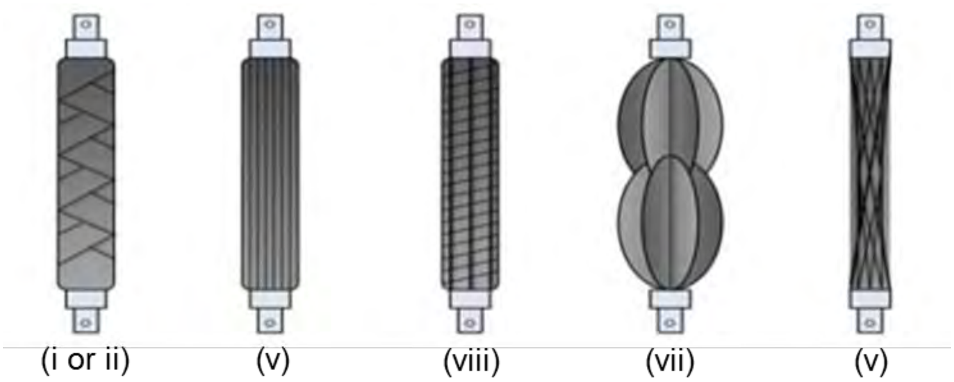

Figure 2.1: Variations of pneumatic muscle actuators [4]

The variations of muscle introduced is due to attentions received by PMA over the past decades. For each variance, they exhibit different mechanical structure and also mathematical model governing the working operations of the muscle.