DESIGN OF BIOMIMICRY ROBOTIC EYE USING THIN MCKIBBEN ACTUATORS WITH AGONIST-ANTAGONIST MUSCLES

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DEDICATION

This project report is dedicated to my parents, who always provided me with the love and support to always strive on and move forward in life. It is also dedicated to my sister, who have always help and support me from behind the scenes. I would not have been able to do this without any of them by my side.

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ABSTRACT

The human eye is important to the survival and evolution of humanity. Thus, we look to it for inspiration in designing and translating its design into a robotic system that can be actuated by soft actuators. The purpose of this study is to investigate and implement biomimicry of the human eye through a 3D printed robotic eye based on a ball joint system that is actuated by thin McKibben actuators with agonist and antagonist muscles. This study proposes the implementation of the agonist-antagonistic as well as neutralizer muscles pairs to actuate the robotic eye through the control of air pressure at 200 kPa and 420 kPa investigate the behaviour of the thin McKibben actuators during the implementation of the agonist-antagonist muscles as well as the assessment of its performance via the laser pointer experiment and Tracker application. The solution is based on the advantage gained through the implementation of the thin McKibben actuators as well as 3D printing during the robotic eye design, which grants an improved, simpler design to the robotic eye. The approach has several notable merits, namely a reduction in design complexity and reduction in size. A comprehensive verification via experimentation was carried out to determine the effectiveness of the concept and design. The result confirms that the method can produce a robotic eye design that works well through the use of agonist-antagonist muscles pairs and neutralizer muscle pairs. From the experimentation works, it was found that the 3D printed robotic eye can be actuated via the Thin McKibben actuator with the angular movement of around 20 degrees and with two Degrees of Freedom via Agonist-Antagonist muscle pairing. The results also show the high repeatability of the robot while operating under hysteresis mode, with a standard deviation of 0.1 to 0.54 after repeated testing. Furthermore, the behaviour of the thin McKibben actuators during the implementation of agonist-antagonist muscle action was successfully identified and categorized as contraction, relaxation and re-contraction behaviours. The method proposed in this paper can be implemented in other types of robots with thin McKibben muscles as actuators as well.

ABSTRAK

Sistem visual manusia adalah amat penting kepada survival dan evolusi manusia. Oleh itu, kita merujuk kepadanya untuk inspirasi dalam mereka cipta sistem visual robotik yang boleh disesuaikan dalam sistem robot yang menggunakan penggerak lembut dengan otot agonis-antagonis. Kajian ini dijalankan dengan tujuan implementasi biomimikri kepada sistem pergerakan mata manusia dengan penggunaan robot mata berdasarkan sendi mata yang dihasilkan melalui percetakan 3D dan manipulasi penggerak nipis McKibben. Kajian ini mencadangkan kaedah implementasi otot agonis dan antagonis serta otot peneutralan untuk menggerakan system robot mata melalui kawalan tekanan udara dalam 200 kPa dan 420 kPa, dan juga menyiasat tingkah laku penggerak McKibben nipis semasa implementasi otot agonis-antagonis serta menilai prestasi robot mata dengan menggunakan kaedah eksperimen penunjuk laser dan applikasi Tracker . Keupayaan robot ini dapat dicapai hasil daripada implementasi penggerak McKibben nipis dan percetakan 3D dalam process reka cipta robot yang mengizinkan reka cipta yang lebih baik dan mudah kepada mata robotik ini. Pendekatan ini mempunyai beberapa merit yang ketara, iaitu pengurangan kerumitan reka bentuk dan pengurangan saiz. Pengesahan menyeluruh melalui eksperimen dijalankan untuk menentukan keberkesanan konsep dan reka bentuk. Hasil eksperimen mengesahkan bahawa konsep pasangan otot agonis-antagonis serta otot peneutralan berjaya dilaksakan. Dari hasil eksperimen, didapati bahawa robot mata yang dicetak 3D dapat digerakkan melalui penggerak McKibben nipis dengan pergerakan sudut sekitar 20 darjah dan dengan dua Darjah Kebebasan menggunakan pasangan otot agonist dan antagonist. Tambahan lagi, tingkah laku penggerak nipis McKibben semasa operasi pasangan otot agonis-antagonis juga berjaya dikenal pasti dan dikategorikan sebagai pengecutan, kelonggaran dan pengecutan semula. Kaedah yang dicadangkan dalam kajian ini juga boleh dilaksanakan dalam jenis robot yang menggunakan penggerak nipis McKibben juga.

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LIST OF ABBREVIATIONS

PAM - Pneumatic Artificial Muscle
MAM - McKibben Artificial Muscle
3D - Three-Dimensional
PLA - Polylactic Acid
ABS - Acrylonitrile Butadiene Styrene

LIST OF SYMBOLS

cm	-	Centimetre
mm	-	Millimetre
kPa	-	Kilopascal
N	-	Newton (force)
%	-	Percentage symbol
C	-	Circumference of the Circle
HA	-	Desired Contraction for the McKibben Actuator during Half Actuation
LH	-	The thin McKibben actuator length for half actuation
FA	-	Desired Contraction for the McKibben Actuator during Full Actuation
FH	-	The thin McKibben actuator length for Full actuation

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

The human visual system is a very complex visual system, with the human eye acting as a light sensor to capture light of certain wavelength, around 400 to 700 nanometres [1] from the environment and feeding it into the central nervous system for further processing via the optic nerves [2]. The human eye or eyeball movement is controlled by six extraocular muscles, with the four extraocular muscle consisting of the superior rectus, lateral rectus, inferior rectus and medial rectus controlling the movement in the four cardinal directions (up, down, left and right) [3]. The extraocular muscles enable movement in the eye via contraction and the muscles work together as agonist-antagonist pairs to facilitate eye movement in the desired direction.

The biomimicry is the study of understanding of the design principles that govern the biological systems and extract the components of the biological design into an engineering or research design [4], [5]. As the human eyes play great importance in human daily lives, it is to no surprise that the human eye has inspired much research into robotic eye [6–10] designs.

The thin McKibben actuator was first introduced in the paper by Takaoka *et. al*, 2013 [11] is a pneumatic artificial muscle that was designed to be lightweight, thin and flexible. It has been used in numerous biomimicry designs such as human hand [12], octopus arm [13], long-legged hexapod Giacometti robot [14], and so on. While there are many works that are based on the human body, there is not much focus in research in regard to the application of thin McKibben actuators in the biomimetic field are for the human eye. Furthermore, while there are many research in regards to biomimetic human eyes, the potential of thin McKibben actuators being applied into a similar design has not been fully explored. This presents an interesting area to research in regards to the potential of the thin McKibben actuators compared to other pneumatic artificial muscles or soft actuators.

The biomimicry of human eyes using soft actuators is a field that has potential for further exploration especially with the advent of 3D printing that enables the easy fabrication of custom plastic parts via a 3D printer, which when applied together with thin McKibben actuator has the potential to bring about a light-weight, customizable design with low manufacturing and design downtime. Furthermore, the application of thin McKibben actuators in a agonist-antagonistic muscle pairing in a ball joint is an area that has potential for further research and study, thus creating an interesting prospect of research in biomimetic robotic eye actuated by thin McKibben actuator.

Lastly, while the current soft robotic technology has not entered consumer stage application it has great potential for growth, development and application. It is hoped that the research in a biomimetic robotic eye that is actuated by thin McKibben actuators could be a small tiny step towards the application of soft robotics in the field of aerospace, deep-sea exploration, human bionic implants and more.

1.2 Problem Statement

The thin McKibben actuator has been applied in many bio-inspired and biomimetic systems, but there has been less focus on the study of its application in a biomimetic or bio-inspired robotic eye. Furthermore while there are many instances of robotic eye that is actuated by pneumatic artificial muscles and soft actuators [7–10], they were designed with larger pneumatic artificial muscles in mind, this there is an opportunity to apply the thin McKibben actuators in a bio-inspired robotic eye system that uses a ball joint structure as the main pivoting element for rotational motion.

Secondly, the robotic eye would be a good chance to showcase the implementation of the agonist-antagonist muscle relationship using thin McKibben actuators in a system using a ball joint structure as the main pivoting element. The implementation of agonist-antagonist muscle pairing using pneumatic artificial muscles and McKibben actuators is not new and has been done by many different researchers, however, there is still room for further study regarding the usage of thin McKibben actuators being used as agonist-antagonist muscle pairs in a ball joint based system. Furthermore, controlling a ball joint based system solely with agonist-antagonist pairing might be hard, and as such, there is opportunity to apply and study thin McKibben as neutralizer muscles to help reduce unnecessary movement in the robotic eye during actuation. Moreover, the behaviour of the thin McKibben actuators during the implementation of such muscles pairing is not deeply explored and warrants further investigation and testing.

Lastly, the performance of the 3D printed biomimetic robotic eye based on a ball joint system needs to be assessed. The proper methods to test the performance of the actuation of the robotic eye has to be developed and compared with other verification methods that are being used in the field.

1.3 Research Objectives

The objectives of the research are:

(a) To develop a 3D printed robotic eye with 2 Degree of Freedom that can be actuated by thin McKibben Pneumatic Artificial Muscle.

(b) To implement and investigate Agonist and Antagonistic muscle pairs as well as Neutralizer muscles relationships in a 3D robotic eye.

(c) To evaluate the performance of the 3D printed robotic eye that is actuated by thin McKibben actuators.

1.4 Research Scope

The scope of the research are:

(a) The human eye is very complex, design characteristics of the eye robot model will be limited to 2 Degrees of Freedom (up, down, left, right movement.)

(b) The total length of the McKibben actuators in this study will be within 14 cm to 15.8 cm. This is due to the difficulty in fabrication of the McKibben actuators.

(c) The robot will take inspiration from the human eye and will be fabricated via 3D printing using PLA material.

(d) The implementation of Agonist and Antagonist, as well as Neutralizer muscle, will be done via manipulation of the McKibben actuators at two pressure points, 200 kPa as well as 420 kPa.

(e) Validation of the robotic eye performance will come via two methods, which are laser pointer measurements and the Tracker application software.

1.5 Operational Definition

Some of the operational definition used is as follows:

(a) Up thin McKibben: The thin McKibben actuator attached to the top portion of the eyeball structure of the robotic eye. Its main function is to pull the robotic eye upwards.

(b) Down thin McKibben: The thin McKibben actuator attached to the bottom of the eyeball structure of the robotic eye. Its main function is to pull the robotic eye downwards.

(c) Left thin McKibben: The thin McKibben actuator attached to the left side of the eyeball structure of the robotic eye. Its main function is to pull the robotic eye to the left.

(d) Right thin McKibben: The thin McKibben actuator attached to the right side of the eyeball structure of the robotic eye. Its main function is to pull the robotic eye to the left.

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