BIDIRECTION MODELING AND EXPERIMENTAL ANALYSIS OF UNDERWATER SNAKE ROBOT

ZHANG NA

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DEDICATION

This thesis is dedicated to my parents, who supported me for my further study and taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my father, who encouraged me to be the best person.

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ABSTRACT

Snakes have dedicate body and can maneuver in challenging environments. In this work, a soft snake-like robot is designed to locomote like a biological snake that can be used in search and rescue operation. The soft snake-like for underwater use has advantages of low inertia, high buoyancy, and more structural flexibility. Currently, the use of multi-redundant thin McKibben actuators for soft snake-like robot was not yet explored. Addressing this gap, a soft snake robot model using Finite Element (FE) will be developed. The FE model will be developed and used to investigate the snake bending motions in Matlab Simulink with Simscape Multibody Library (SML). Next, the actual fabrication of the robot will be validated with the simulated FE model using redundant mechanism of 10 McKibben actuators attached on a plastic plate. The structure of this robot uses 32 cm of a thin non-rigid plastic plate with five thin muscles at both sides of the body. Each thin muscle has 2.0 mm outer diameter with internal 1.3 mm silicone tube. The manipulator will be tested with different pressure and frequencies to perform various bending motions. Tracker application will capture every phase of the bending body and movements for analysis of the robot's movement. It is expected that the snake-like robot can move and the errors of bending angle between simulation and experiment are less than 5%.

ABSTRAK

Ular mempunyai badan yang berdedikasi dan dapat bermanuver dalam lingkungan yang mencabar. Dalam karya ini, robot seperti ular lembut dirancang untuk menggerakkan seperti ular biologi yang dapat digunakan dalam operasi serak dan penyelamatan. Seperti ular lembut untuk penggunaan di bawah air mempunyai kelebihan inersia rendah, daya apung tinggi, dan fleksibiliti struktur yang lebih banyak. Pada masa ini, penggunaan penggerak McKibben nipis multi-redudant untuk robot seperti ular lembut belum diterokai. Untuk mengatasi jurang ini, model robot ular lembut menggunakan Finite Element (FE) akan dikembangkan. Model FE akan dikembangkan dan digunakan untuk menyiasat gerakan membengkokkan ular dalam Matlab Simulink dengan Simscape Multibody Library (SML). Seterusnya, fabrikasi sebenar robot akan disahkan dengan model FE yang disimulasikan menggunakan mekanisme redudant 10 penggerak McKibben yang dilekatkan pada plat plastik. Struktur robot ini menggunakan plat plastik nipis tidak tegar 32 cm dengan lima otot nipis di kedua-dua belah badan. Setiap otot nipis mempunyai diameter luar 2.0 mm dengan tiub silikon 1.3 mm dalaman. Manipulator akan diuji dengan tekanan dan frekuensi yang berbeza untuk melakukan pelbagai gerakan lenturan. Aplikasi tracker akan menangkap setiap fasa badan lenturan dan pergerakan untuk analisis pergerakan robot. Dijangkakan robot seperti ular dapat bergerak dan kesalahan sudut lenturan antara simulasi dan eksperimen kurang dari 5 %.

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LIST OF ABBREVIATIONS

UTM	-	Universiti Teknologi Malaysia
FE	-	Finite Element
SML	-	Simscape Multibody Library

LIST OF SYMBOLS

n	-	Factor Accounting for the End Conditions
N	-	Amount of Phases of the Truth Table
k	-	Amount of the Actuators
I	-	Moment of Inertia
L	-	Initial Lenghth of the Mckibben Actuator
E	-	Modulus of Elasticity of Polypropylene
α	-	Braid Angle
θ	-	Bending Angle
F_m	-	Allowable Load Force
F_x	-	Allowable Load Force in X-axis
F_y	-	Allowable Load Force in Y-axis
l_1	-	Lenghth of McKibben Actuator
l_2	-	Lenghth of McKibben Actuator in Y-axis
l_3	-	Lenghth of McKibben Actuator in X-axis

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Robots appeared in Rossum's book in 1920 as the first time. In Czech, robots represent slaves [21], which means they are the tool to help human. In our daily life, robots can be widely used in environments which are inaccessible to humans, highly repetitive, and extremely harsh [22]. With the development of seabed resources, underwater robots are highly discussed these years to survey underwater resources, and applied in aquaculture to estimate animal abundance.

Furthermore, many robots are inspired by natural animals. In these bio-inspired robots, snake-like robots are the easier one with simple structure. Snake-like robots shown as Figure 1.1 can be employed to navigate through constrained environments since their structure was flexible and their body was small [1].

Figure 1.1 Snake-like robot with rigid structure [1]

Besides, soft robotics, intended as the use of soft materials in robotics, was a young research field, going to overcome the basic assumptions of conventional rigid robotics and its solid theories and techniques, developed over the last 50 years [3].

Pressure-operated actuators shown as Figure 1.2 had been utilized by Ming et al., which also named as Pneumatic Artificial Actuators, Axially Contractible Actuators [2]. Mckibben actuators are the series of pressure-operated actuators. Applying soft actuators in robotics is a kind of soft robotic. In this project, novel design of snake-like robot using McKibben actuators have been proposed.

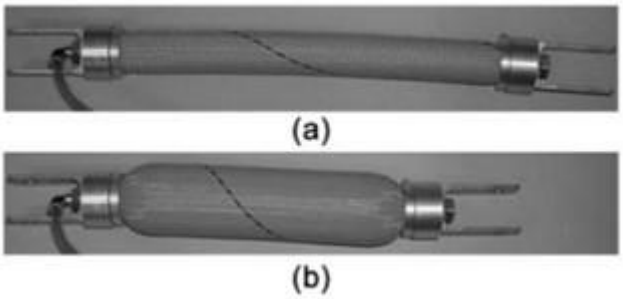

Figure 1.2 General structure of soft actuator [2]

To study the characteristics of McKibben actuator, there are some mathematical models. FE model is the most popular model when studying on McKibben actuator.

Even though an excellent account of FE models have been proposed, they focused more on the relationship between force and some constant values like length and diameter or variable values like friction. Furthermore, the braid angle was the critical parameter to obtain the contraction model of the actuator [23]. Meanwhile, FE model performed in 2D form and only showed the main view of deformation. With the maturation of applications like Solidworks, Ansys, and Matlab, the 3D animation model also available in our generation [24].

In this project, Simscape Multibody Library (SML) in Matlab Simulink was carried out, compared to Solidworks and Ansys, fewer researchers utilized Matlab to perform 3D animation [25]. The simulation using SML demonstrated divergent views of the bending experiment [26]. Finally, analyzing the bending experiments' properties by Tracker application.

1.2 Problem Statement

Snake-like robots have been widely used in marine exploration, underwater inspection and maintenance, search and rescue, and other fields. There were many projects about snake-like robots, however, most designs of the snake-like robot were developed by motors. Compared to hard actuator such as motors, soft actuators are less-weight and water-proof. Soft actuators such as McKibben actuators were utilized to develop non-rigid snake-like robot.

However, several snake-like robots developed by soft actuators only focused on the movement on the ground. Besides, the movement of snake-like robot also helped by several wheels, which was different from the natural snake. Moreover, currently, the usage of multi-redundant thin McKibben actuators for soft snake-like robot was not yet explored.

In this project, a developed FE model with SML in Matlab has been proposed to model the snake-like robot motion. Then, a real snake-like robot fabricated with plastic ruler and several McKibben actuators was designed in this project which can be used underwater. After that, bending tests on both simulation and experiment were carried out. Furthermore, forward speed of snake-like robot under different pressures and different frequencies were carried out.

1.3 Research Objectives

Based on the problem statement, the following research objectives are recognized as a yardstick for the researchers to fulfill the study.

(a) To develop a snake-like robot model in Matlab Simulink using SML.

(b) To fabricate and analyze snake-like robot using 10 McKibben actuators attached on a plastic plate.

(c) To validate the performances of simulated and experimental robotic snake using Tracker application.

1.4 Project Scope

The scopes of the research are:

(a) The design of the robotic snake is a plastic plate with 5 McKibben actuators on each side, the McKibben actuators' characteristics are 2.0 mm outer diameter with internal 1.3 mm and 0.1 m length.

(b) The motion of the snake-like robot only have one small semicircle and one big semicircle.

(c) The operating pressure is 0.3 MPa in simulation.

(d) Snake-like robot bending motions' simulation built in Matlab Simulink with SML.

(e) The snake-like robot was tested with different pressures and frequencies.

1.5 Significance of study

Once the project fulfilled, several significance of this project will achieve.

(a) Simulation model using SML of snake robot will be shown, the 3D animation

(b) modelling using SML is more vivid compared to other FE model.

(c) A novel design with the use of multi-redudant thin McKibben actuators for soft snake-like robot will be fabricated.

(d) The simulation results can be used to predicted the relationship between the bending angle and the location of the joint.

(e) Low error shows that the simulation is suitable for testing experiment.

1.6 Organization of the Report

This thesis consist of five chapters and the following chapters are organized as follows:

Chapter 2 introduces the principles of the soft continuum robots, snake-like robots, natural snake gaits, McKibben actuator, and the FE method from the literature of this study.

Chapter 3 describes briefly how the research would be carried out regarding the research design. It composed of four parts. First, fabrication of one McKibben actuator. Second, simulation of snake-like robot using SML in Matlab. Third, fabrication of snake-like robot and experiments tests. Tracker application analysis at last.

Chapter 4 displays and discusses the results we got and utilized the Tracker application to analyze the bending motions from the simulation and experiment. Besides, Tracker application was utilized to check the forward speed of snake-like robot under different pressures and different frequencies.

Chapter 5 summarizes and concludes the overall project as well as achievements of objectives and the future work which need to do.

1.7 Summary

This chapter has provided the framework for this project. Firstly, it gave the introduction and background of this project and introduced the most important definitions. Then, the importance and significance were explained. Moreover, the problem statement has explained the gap between previous studies and this research. Thus this project aimed to fulfill the objectives.

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