POSITION CONTROL OF HUMAN-LIKE ROBOTIC HAND INDEX FINGER USING MACHINE LEARNING

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DEDICATION

This project report is dedicated to my father, who 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 mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

The hand has been a great tool for humans with the advantage of dexterous function and power to do daily activities such as turning a doorknob, wearing clothes, using a screwdriver and picking up objects. These dexterous hand motions are achieved due to the biomechanics of hands and redundant mechanism of hand muscles. These muscles receive brain signals and react accordingly to perform different hand motion gestures when dealing with different objects. Sub-conscious mind in our brain instructs actuation of different extrinsic and intrinsic muscles in order to move our fingers to different positions for desired functions. The index finger plays an important role in performing hand gestures for human daily activities. This work presents position control of index finger of human-like robotic hand (HR Hand) using machine learning. The HR Hand is a replication of the human hands in terms of bones, ligaments, muscles, extensor mechanism, tendon and its pulley system. The muscles of the hand were fabricated using thin multifilament McKibben muscles following design of index finger by A.A.M. Faudzi. Motion of the HR Hand is captured using Vicon^{TM} motion capture to build a K-nearest neighbour (KNN) and Artificial Neural Network (ANN) model. This model is used to predict the combination of muscles used for fingertip position control. Hyperparameter optimization is done using grid search method to obtain better accuracy. The ANN model showed to have better accuracy of 71.36 % in predicting actuation of muscle class compared to the 65.38 % by KNN. The ANN model is applied in building a feed-forward controller and verified on the system with 2.7 cm steady state error. Using this model, future control of HR Hand is expected.

ABSTRAK

Tangan merupakan alat yang penting untuk manusia dalam melakukan fungsi dengan tangkas dan melakukan aktiviti harian seperti memutar tombol pintu, memakai pakaian, menggunakan pemutar skrew dan mengambil objek. Gerakan tangan yang tangkas ini dicapai melalui biomekanik dan mekanisme berlebihan otot tangan. Otot-otot ini menerima isyarat daripada otak dan seterusnya bertindak balas untuk melakukan gerakan tangan yang berbeza ketika berurusan dengan objek yang berbeza. Fikiran separa sedar dalam otak kita mengaktifkan otot-otot ekstrinsik dan intrinsik untuk menggerakkan jari ke pelbagai kedudukan dan posisi yang diingini. Jari telunjuk memainkan peranan penting dalam membuat gerak isyarat untuk aktiviti-aktiviti harian manusia. Kerja ini memaparkan pengawalan kedudukan jari telunjuk tangan manusia seperti robot (tangan HR) melalui pembelajaran mesin. Tangan HR ini adalah pereplikaan tangan manusia dari segi tulang, ligamen, otot, mekanisme ekstensor, tendon dan sistem takalnya. Otot-otot tangan direka menggunakan otot nipis McKibben filamen pelbagai dan reka bentuk jari telunjuk oleh A.A.M. Faudzi. Pergerakan tangan HR direkod menggunakan rakaman gerakan Vicon™ untuk membina model algoritma Tetangga K-Terdekat (KNN) dan Model Rangkaian Neural Buatan (ANN). Model ini digunakan untuk meramal kombinasi otot yang digunakan untuk kawalan kedudukan hujung jari. Pengoptimuman hiperparameter dilakukan melalui kaedah carian grid untuk mendapat ketepatan yang lebih tinggi. Model ANN mepaparkan ketepatan yang lebih tinggi iaitu 71.36 %, dalam meramalkan gerakan kelas otot berbanding dengan model KNN iaitu 65.38 %. Model ANN digunakan dalam membina kawalan suap depan dan disahkan dengan 2.7 cm sistem ralat keadaan mantap. Dengan mengunakan model ini, kawalan penuh tangan HR dijangkakan pada masa hadapan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APH	-	Anthropomorphic Prosthetic Hand
DRH	-	Dexterous Robotic Hand
HR Hand	-	Human Like Robotic Hand
CNS	-	Central Nervous System
AI	-	Artificial Intelligence
ANN	-	Artificial Neural Networks
MCP	-	Metacarpophalangeal
DIP	-	Distal Inter-Phalangeal
PIP	-	Proximal Inter-Phalangeal
ROM	-	Range Of Motion
CMC	-	Carpometacarpal
DOF	-	Degree Of Freedom
PSU	-	Position Sensing Unit
ACU	-	Actuator Control Unit
HCU	-	Hand Communication Unit
MCI-DNN	-	Multi-Context Deep Neural Network
RNN	-	Recurrent Neural Network
FNN	-	Feed-forward Neural Network
DNN	-	Deep Neural Network
NR	-	Nuclear Receptor
SR	-	Stress Response
AM	-	Ames Mutagenicity
AUC	-	Area Under Curve
FDP	-	Flexor Digitorum Profundus
FDS	-	Flexor Digitorum Superficialis
EDC	-	Extensor Digitorum Communis
EI	-	Extensor Indicis
ECRL	-	Extensor Carpi Radialis Longus
FCR	-	Flexor Carpi Radialis

LIST OF SYMBOLS

L	-	Length
D, d	-	Diameter

CHAPTER 1

INTRODUCTION

1.1 Introduction

The human hand plays a vital part in our everyday lives. Daily task such as carrying objects, turning door knobs, cooking and typing can be done by the human hand. Complicated tasks which need great dexterity such as precisely using a screw driver can also be accomplished by the human hand. The key to achieving high dexterity of the human hand is the biomechanics of the hand and the muscles involved (Bicchi, 2000). Having great dexterity and such ability to execute daily task in human's everyday life leads to vigorous study to imitate the human hand. Roboticist studying the function and application of robotic hand divided them into two main areas, Anthropomorphic Prosthetic Hands (APH) and Dexterous Robotic Hand (DRH) (Bicchi, 2000).

Currently, research on humanoid robots that imitate human drive mechanisms is enthusiastically carried out globally. The conventional approach of design in the robotic hand field usually replaces complicated human parts by mechanical components such as linkages, hinges, gimbals and use motor as an actuation method. Although this method may be accommodating for man-kind where it improves our understanding and approximation of the human hand kinematics in general, however this actually introduces objectionable differences with the actual human hand. Recent robotic hands that can demonstrate human levels of dexterity are very few, while most of them are task-based operations include KITECH-Hand (Lee, Park, Park, Baeg, & Bae, 2017).

McKibben-style actuators characterized by its high-level functional analogy with human skeletal muscle are of interest. The actuator also has passive and natural compliance, which follows the nature of skeletal muscle. The Human like Robotic

Hand (HR Hand) closely follows the human hand by replacing the use of motors with McKibben style actuator. The HR hand is a replication of the human hands in terms of bones, ligaments, muscles, extensor mechanism, tendon and its pulley system. The bones are replicated by using readily available upper limb model from actual specimen of 160cm human male adult while the ligaments are fabricated from 1mm silicon of McKibben muscles to attain similar stiffness to human ligaments. The muscles of the hand are fabricated using thin multifilament McKibben muscles (A. A. M. Faudzi, Ooga, Goto, Takeichi, & Suzumori, 2018).

In 2019, (Abdulrab, 2019) used the concept of the HR hand to improve the HR hand with pinching motion by adding a thumb to the existing index finger. The HR Hand has been improved where the number of available gestures has increased for pinching motion. Electro-pneumatic regulators were also added to the HR Hand where manual tuning of potentiometers are done to control the muscle contraction. The selection of muscles to be actuated are also carefully chosen by the operator. However, this differs to the nature of muscle selection in humans. This will be further discussed in the problem background.

1.2 Background of Problem

The HR Hand closely follows the anatomy of the human hand by ligaments, bone structure and the use of McKibben actuators. However, the current HR hand uses manual control to select actuation of muscles. This creates complexity as there exist too many muscles in the human hand. In humans, the central nervous system (CNS) acts as a controller where a desired set point position is determined in the brain and the CNS sends neural signals to the correct muscles to be actuated either by means of contraction or relaxation. This element of control is attached to the individuals experience, training or knowledge (Balderas & Rojas, 2016). Machine learning has high similarity to the muscle control where the prediction made is based on training of past data. This work presents control of HR Hand index finger using machine learning. The next section will further discuss the problems in implementing machine learning for HR Hand position control.

1.3 Problem Statement

The HR Hand Index finger by (A. A. M. Faudzi, J. Ooga, et al., 2018) was developed on a single index finger to study the similarities of the design compared to the human index finger. Three extrinsic muscles was used to validate the properties of the index finger and to study the sweep motion to resemble the real human finger.

In order to achieve better similarity with humans, the control mechanism should be upgraded form the previous manual triggering to a more human-like control method. Machine learning can be applied to control the motion of the HR Hand index finger to achieve better similarity with humans. However, in order to obtain this comparison, extrinsic muscle origins should be considered in the design of the HR Hand. As the previous work was not intended for big data collection, the HR hand design needs to be enhanced to suit data collection in order to apply machine learning control.

Similar to the human index finger, the HR Hand index finger is actuated by muscles that are attached to bones by tendons. The actuation of each muscle with different contraction determines the movement position of the finger and joints. (Shalev-Shwartz & Ben-David, 2014) stated that machine learning is suitable for tasks that are too complex to program such as tasks performed by humans and animals. As there are too many muscles and muscle combination to control individually, machine learning may simplify the control of the HR Hand.

The accuracy of the model for muscle actuation is not enough to verify if the machine learning model is suitable for position control of the HR Hand. The model should be applied to build a controller for the HR Hand and the actual position should be compared to the set point position. These problems led to the development of the research objectives.

1.4 Research Objectives

The objectives of the research are:

(a) To fabricate the HR Hand index finger flexion and extension using McKibben muscle.

(b) To develop machine learning model using KNN and ANN for index finger position control based on Vicon™ motion capture data.

(c) To control the index finger position using feed-forward controller and validate the position experimentally.

1.5 Scope of the Study

The project scope are as below:

(a) Only extrinsic muscle of right index finger is considered in the fabrication of the HR Hand using 4.0 mm McKibben muscle.

(b) Control of HR Hand position is focused on the right index finger tip in static and fixed environment.

(c) McKibben muscles are controlled using on/off valves with constant pressure of 0.3 MPa.

(d) MATLAB function *nprtool* and *fitcknn* is used to build the machine learning models of ANN and KNN.

1.6 Operational Definition

Some operational definitions are as below:

(a) Artificial Intelligence (AI): A wide ranging branch of computer science concerned with building smart machines capable of performing tasks the typically require human intelligence.

(b) Machine learning: Application of AI that provides systems the ability to automatically learn and improve experience without being explicitly programmed.

(c) Artificial neural network (ANN): Mathematical models which match the learning process in biological neurons. The ANN model are trained to learn knowledge for pattern recognition, values prediction, data validation and classification.

(d) Humanoid robot: Robot developed to resemble humans closely.

1.7 Significance of Study

The significance of this work are as below:

(a) This study is related to health and wellness where musculoskeletal system could give robotics alternative solution for medical student other than using real cadaver model.

(b) The study enhances the HR Hand for automated positioning control using machine learning approach.

1.8 Chapter Summary

This chapter had discussed the background problem of the study that led to the problem statement. Three research objectives were put forward to assist the direction and tighten the scope of the research. The operational definition define the terms used in the study and helps to explain the significance of the study. This will be explained clearly in the literature review.

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