Faculty of Electronic and Computer Engineering

MULTI-FINGER LOCALIZATION FEEDBACK THROUGH VIBROTACTILE SENSORY SUBSTITUTION SYSTEM FOR PROSTHETIC HAND

Yusof bin Yunus

Master of Science in Electronic Engineering

2021

MULTI-FINGER LOCALIZATION FEEDBACK THROUGH VIBROTACTILE SENSORY SUBSTITUTION SYSTEM FOR PROSTHETIC HAND

YUSOF BIN YUNUS

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

Faculty of Electronic and Computer Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this thesis entitled "Multi-Finger Localization Feedback through Vibrotactile Sensory Substitution System for Prosthetic Hand" 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 the candidature of any other degree.

Signature : ....

Name : ....

Date : ....

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 Electronic Engineering.

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATION

I dedicate this thesis to my loving family, my lover, and my beloved friends for their constant support and unconditional love.

ABSTRACT

Executing daily life activities is very challenging for those who missing their limbs due to amputation. Prosthetic technology becomes one of the alternative ways to replace the missing limb. However, recent prosthetics technology is still unable to meet the requirement of user due to less functionality especially lack of sensory feedback. This research is to develop and analyse the vibrotactile sensory substitution system for multi-finger localisation feedback. Previous study has shown the capability of vibrotactile feedback as one of the successful method. The system developed must have accessible control of many parameters such as vibratory frequency, number of active motors and sequence of stimulation. Four experiments are conducted in this research. The first experiment is to study the relationship between input duty cycle injected to the motor and the vibratory frequency produces by the actuators. Next experiment is to evaluate the finger localisation by using three parameters (vibratory frequency, vibrotactile configuration and type of actuator). The third experiment is to evaluate five different designs of vibrotactile pattern stimulation (VPS) composed of different rhythm and burst actuation time. The last experiment is to evaluate the system on slipping detection. The key outcome measures for this research are recognition rate (accuracy) and Information Transfer (IT). The results show that the higher the vibratory frequency, the better the recognition rate and IT for ERM motor with 8% difference in score. Although, there is no significant difference between LRA and ERM motor, LRA motor is chosen due to its better performance and smaller size. The best VPS in experiment three are VPS4 and VPS5 due to its high accuracy score and IT. VPS4 score is 1.79 bits and VPS5 score is 1.63 bits while the other VPS score less than 1.2 bits. The system designed is applicable for slipping detection. The findings from this research provide an enhancement for haptic feedback development in prosthetic hand.

MAKLUM BALAS PENYETEMPATAN JARI-JEMARI MELALUI SISTEM PENGGANTIAN DERIA TAKTIL GETARAN UNTUK TANGAN PROSTETIK

ABSTRAK

Melaksanakan aktiviti harian adalah mencabar bagi mereka yang kehilangan anggota badan. Teknologi prostetik menjadi salah satu alternatif untuk menggantikan anggota yang hilang. Walau bagaimanapun, teknologi prostetik masa kini masih tidak dapat memenuhi keperluan pengguna kerana kekurangan fungsi terutamanya kelemahan maklum balas deria. Kajian ini adalah untuk mereka bentuk, membangunkan dan menganalisa sistem penggantian deria vibrotactile untuk maklum balas lokasi jejari. Kajian terdahulu telah menunjukkan keupayaan maklum balas vibrotactile sebagai salah satu kaedah yang berjaya. Sistem penggantian deria vibrotactile direka untuk mempunyai kawalan yang boleh diakses dari banyak parameter seperti kekerapan getaran, bilangan motor aktif dan urutan rangsangan. Empat eksperimen dijalankan dalam kajian ini. Eksperimen pertama adalah untuk mengkaji hubungan antara kitar tugas input yang disuntik ke pemacu motor dan frekuensi getaran yang dihasilkan oleh penggerak. Eksperimen seterusnya adalah untuk menguji penyetempatan jari dengan menggunakan tiga parameter (frekuensi getaran, konfigurasi vibrotactile dan jenis penggerak). Eksperimen ketiga adalah untuk menilai lima reka bentuk corak rangsangan vibrotactile (VPS) menggabungkan irama yang berbeza dan masa motor dihidupkan. Eksperimen terakhir adalah untuk menguji sistem tersebut pada aplikasi tergelincir. Kayu ukur untuk kajian ini ialah kadar pengiktirafan (ketepatan) dan Pemindahan Maklumat (IT). Keputusan menunjukkan bahawa semakin tinggi frekuensi getaran, semakin baik kadar pengiktirafan dan IT untuk motor ERM dengan 8% perbezaan markah. Walaupun, tidak terdapat perbezaan yang signifikan antara motor LRA dan ERM, motor LRA dipilih kerana prestasinya yang baik dan saiz yang lebih kecil. VPS terbaik dalam eksperimen tiga adalah VPS4 dan VPS5 kerana ketepatan yang tinggi dan ketinggian markah IT. Markah VPS4 adalah 1.79 bits dan VPS5 adalah 1.63 bits sementara VPS yang lain mempunyai markah kurang dari 1.2 bits. Sistem yang direka boleh diaplikasikan pada pengesanan tergelincir. Penemuan dari kajian ini memberi peningkatan bagi pembangunan maklum balas haptik dalam tangan prostetik.

ACKNOWLEDGEMENTS

I would like to express my highly appreciation to my main supervisor Assoc. Prof. Dr. Soo Yew Guan who had guided, motivated me throughout the research on image processing and his advice had greatly improved my thesis writing.

Furthermore, I want to thank my lecturers, specially Dr. Ranjit Singh Sarban Singh, Dr. Sani Irwan bin Md Salim and Assoc. Prof. Dr. Lim Kim Chuan for their advice and motivation throughout my research work.

At last, I would like to extend my gratitude to my parents, Mr. Yunus Djaman and Mrs. Masita Basir, my siblings and my friends for their encouragement, love and support. I am grateful to have all these people around me throughout the research. Once again, thank you so much.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BVD	-	Bilateral Vestibular Dysfunction
CNS	-	Central Nervous System
ERM	-	Eccentric Rotation Mass
EMG	-	Electromyography
FA	-	Fast Adapting
FFT	-	Fast Fourier Transform
GUI	-	Graphic User Interface
IT	-	Information Transfer
LRA	-	Linear Resonant Actuator
ME	-	Myoelectric
M	-	Mean
NiMH	-	Nickel Metal Hydroxide
PNS	-	Peripheral Nervous System
PCB	-	Printed Circuit Board
PWM	-	Pulse Width Modulation
RMS	-	Root Mean Square
SA	-	Slowly Adapting
SD	-	Standard Deviation
USB	-	Universal Serial Bus

VPS	-	Vibrotactile Pattern Stimulation
VPS1	-	Vibrotactile Pattern Stimulation 1
VPS2	-	Vibrotactile Pattern Stimulation 2
VPS3	-	Vibrotactile Pattern Stimulation 3
VPS4	-	Vibrotactile Pattern Stimulation 4
VPS5	-	Vibrotactile Pattern Stimulation 5

LIST OF SYMBOLS

dB	-	Decibel
Hz	-	Hertz
mm	-	milimeter
KB	-	Kilobyte
$\boldsymbol{DC}$	-	Direct Current
mA	-	Miliampere
V	-	Volt
kHz	-	Kilohertz
g	-	Standard gravity
$\boldsymbol{n}$	-	Total number of trials
$\boldsymbol{k}$	-	Number of stimulus
$\boldsymbol{n_{ij}}$	-	Cell entry in the $\boldsymbol{i}$-th row and $\boldsymbol{j}$-th column of the confusion matrix
$\boldsymbol{n_i}$	-	Sum of the entries in the $\boldsymbol{i}$ -th row
$\boldsymbol{n_j}$	-	Sum of the entries in the $\boldsymbol{j}$-th column

LIST OF PUBLICATIONS

The research papers produced and published during the course of this research are as follows:

1. Yunus, Y**.,** Soo, Y., Saad, N., Salim, S. and Duan, F., 2017. Multi-Finger Localization Feedback Using Vibrotactile Pattern Stimulation (VPS) for Prosthetic Hand. *Advanced Science Letters*, 23(11), pp.11449-11453. (*Scopus)*

2. Yunus, Y**.,** Soo, Y., Saad, N., 2016. Feasibility Study of Finger Localization Feedback for Prosthetic Hand using Vibrotactile. *ARPN Journal of Engineering and Applied Sciences*, 11(10), pp.6334-6338. *(Scopus)*

CHAPTER 1

INTRODUCTION

1.1 Background

Limb loss due to either congenital or traumatic amputation will limit and individual's quality of life. This will cause negative impact for amputees. Prostheses were able to restore some independence and functionality to amputees. Upper-limb prostheses with myoelectric technology bring opportunity the user to control grasping by using electromyography (EMG) signals obtained from their remaining muscle. Recently, deep research has been done in order to develop prostheses with feedback technology. Many studies have shown that some structures of feedback like force and vibrotactile were able to improved grasping performance (Witteveen et al., 2014; Raspopovic et al., 2014; Hasson and Manczurowsky, 2015; Kim and Colgate, 2015; Nabeel et al., 2016; Rosenbaum-Chou et al., 2016; Markovic et al., 2018; Rayeh et al., 2018; Thomas et al., 2019; Rokhmanova et al., 2019). The performance of prostheses feedback usually based on accuracy and reaction time. However, nowadays there are no existed commercial upper-limb prostheses that were able to contribute extra feedback as an addition to visual feedback (Witteveen et al., 2014). Prosthesis feedback can also be called as haptic (Culbertson et al., 2018).

Haptic sensory system was developed based on inputs that come from sensory and motor activity that includes sensors in the muscle, skin and joints. Figure 1.1 shows the overview of haptic sensory system. Unlike the visual sense, haptic sensory system is a dual communication channel which means the system able to sense and act on stimuli. The cutaneous or tactile senses are bonded by the 'sense of touch' and inputs which a direct contact with human skin (Dahiya and Valle, 2012). Four basic features of stimulation that can be detected by tactile sense: thermal, mechanical, chemical and electrical. Proprioceptive or kinesthetic perception is refers to sensation of position, forces and velocity come from receptors in tendons and muscle. Tactile and proprioceptive senses play a major role in our daily live activities. The haptic senses deliver us important information to interact with the environments.

Haptic interface or haptic feedback is a device that can transmit haptic sensations. It can communicate with a user by transmit kinaesthetic or/and tactile perceptions. These devices can be used for wide range applications which include the tele-operation of robotic systems and virtual environments. Haptic interfaces able to deliver tactile or force feedback to the user or receive the user's response to deliver relevant feedback. Tactile displays deliver information about the interaction at a contact point. One of the successful applications of tactile display for sensory substitution is deliver spatial information in the absence of visual information. The example of tactile sensory substitution device is refreshable Braille display for blind people (Vidal-Verdu and Hafez, 2007).