

Development of an EEG signal based Brain Machine Interface for a Meal Assistance Robot

Kaluarachchige Don Chamika Janith Perera

168024V

Degree of Master of Science

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

August 2018

Development of an EEG signal based Brain Machine Interface for a Meal Assistance Robot

Kaluarachchige Don Chamika Janith Perera

168024V

Thesis submitted in partial fulfillment of the requirements for the degree Master
of Science in Biomedical Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

August 2018

DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the MSc thesis under my supervision.

Signature of the Supervisor(s):

Date:

Dr. Thilina Lalitharathne

Senior Lecturer

Department of Mechanical Engineering

University of Moratuwa

Abstract

Most of the countries in the world are facing the problems of aging population and disabilities among the population. Among different problems faced by these individuals, self feeding can be identified as an important aspect that should get more attention from the research community. In addition, self feeding reflects the interdependency of an individual and thus relate to their mental health. Taking care of these individuals using care takers is becoming more and more difficult due to diminishing workforce for such tasks. Therefore assistive robotic technologies play a major role in providing feeding solutions to these individuals with disabilities. Meal assistance robot is a device designed to assist the individuals in need with self feeding.

The research work of this thesis is focused on developing an EEG signal based Brain Machine Interface for a meal assistance robot. Meal assistance robot is capable of handling solid food items using the spoon mounted on the end effector. Identifying user's food selection is carried out using a Steady State Visually Evoked Potential based Brain Machine Interface where 3 LED matrices flicking at 6Hz, 7Hz and 8Hz are used to generate the stimulations in the brain. User has to gaze at a LED panel to activate the motion path of the robot which will feed the solid food from the container associated with the gazed LED panel. System is incorporated with a visual servoing algorithm to identify the user's mouth position and adapt the food feeding location according the mouth location. Further, Mouth open/close status detection system is developed to measure the user's willingness to intake the food. The developed meal assistance robot is experimentally validated using 15 subjects in different experiments.

After detailing the research methods carried out, discussion of the results obtain are presented at the end of the thesis with limitations of the research and possible future improvements.

Keywords-Meal Assistance Robot, SSVEP, visual servoing, EEG

DEDICATION

This dissertation is dedicated to my parents, to whom i can trace my every
success to.

ACKNOWLEDGMENTS

First and foremost I offer my sincerest gratitude to my supervisor, Dr Thilina Lalitharatne, who has given me the opportunity to follow my MSc in University of Moratuwa and who supported me throughout my thesis with his patience and knowledge whilst allowing me the room to work in my own way. I attribute the level of my Masters degree to his encouragement and effort and without him this thesis, too, would not have been completed or written. One simply could not wish for a better or friendlier supervisor.

Besides my supervisor, I would like to thank the rest of my progress review committee: Prof. Ruwan Gopura, Dr. Anjula De Silva, and Dr.Damith Chathuranga, for their insightful comments and encouragement, but also for the hard question which encouraged me to widen my research from various perspectives. My sincere thanks also goes to Assistant Professor Chinthaka Premachandra for offering me a summer internship opportunity at Shibaura Institute of Technology, Japan and leading me working on diverse exciting projects.

Special gratitude must be given to my lab members in Bionics Laboratory, Department of Mechanical Engineering Dr. Kanishka Madusanka, Achintha Mihiaran, Isuru Ruhunage, Sanka Chandrasiri, Achintha Iroshan, Thilina Weerakkody, and Dinesh Kumara for their support towards me in participating for experiments as subjects. Futher, I would like to thank my final year research group member Isira Naotunna for initiating this research with me. Also I would like to thank Dr. Viraj Muthugala for his helpful insights on the research. Finally, I thank my parents for supporting me throughout all my studies at University.

TABLE OF CONTENTS

| | |
|---|-------------|
| Declaration | i |
| Abstract | ii |
| Dedication | iii |
| Acknowledgments | iv |
| Table of Contents | viii |
| List of Figures | xi |
| List of Tables | xii |
| Abbreviations | 1 |
| 1 Introduction | 3 |
| 1.0.1 Contributions of the Thesis | 6 |
| 1.0.2 Thesis Overview | 6 |
| 2 Literature Review | 9 |

| | | |
|----------|---|-----------|
| 2.1 | Mechanical design of meal assistance robots. | 11 |
| 2.1.1 | Feeding methods | 11 |
| 2.1.2 | Food storage method | 13 |
| 2.1.3 | Actuation methods used in meal assistance robots | 15 |
| 2.1.4 | Summary | 15 |
| 2.2 | Controlling methods of meal assistance robot. | 17 |
| 2.2.1 | User input identification methods used in meal assistance robots. | 17 |
| 2.2.2 | Hardware control of the meal assistance robots. | 20 |
| 2.2.3 | Emerging technologies in meal assistance robots. | 21 |
| 2.2.4 | Use of Brain Machine Interfacing as a control signal. | 22 |
| 2.2.5 | Event-related potentials (ERPs) | 24 |
| 2.2.6 | Sensorimotor rhythms (SMR) | 25 |
| 2.2.7 | Steady State Visually Evoked Potential (SSVEP) | 27 |
| 2.2.8 | Summary | 27 |
| 3 | Overview and hardware design of the proposed meal assistance robot | 29 |
| 3.1 | Introduction | 29 |
| 3.2 | Overview of the proposed meal assistance robot | 29 |
| 3.3 | Mechanical design and controlling of the 4DOF meal assistance robot | 33 |

| | | |
|----------|---|-----------|
| 3.3.1 | Mechanism and Mechanical Design | 34 |
| 3.3.2 | Kinematic analysis of the meal assistance robot | 36 |
| 3.3.3 | Controlling of the meal assistance robot | 41 |
| 3.3.4 | Electrical component connections | 42 |
| 4 | Development of user intention detection method using EEG:SSVEP based BMI | 44 |
| 4.1 | Introduction | 44 |
| 4.2 | Selection of the stimulation frequency | 45 |
| 4.3 | Visual stimuli generation | 46 |
| 4.4 | Acquisition of EEG signals. | 47 |
| 4.5 | Preprocessing of acquired raw signals | 52 |
| 4.6 | Feature extraction and classification of SSVEP signal | 54 |
| 4.6.1 | Fast Fourier Transformation based SSVEP classification | 54 |
| 4.6.2 | Canonical correlation based SSVEP classification | 55 |
| 5 | Vision based mouth position identification and mouth open/close identification | 59 |
| 5.1 | Introduction | 59 |
| 5.2 | Automatic mouth position identification and tracking | 59 |
| 5.3 | User mouth open/close detection | 63 |

| | |
|---|-----------|
| 6 Experiments, results and discussion. | 65 |
| 6.1 Discussion | 77 |
| 7 Conclusion and Future Work | 80 |
| 7.1 Conclusion | 80 |
| 7.2 Future directions | 82 |
| A First Appendix | 83 |
| A.1 Forward kinematics equations | 83 |
| A.2 Inverse kinematics equations | 84 |
| List of Publications | 85 |
| Bibliography | 94 |

LIST OF FIGURES

| | | |
|-----|--|----|
| 1.1 | World population projection for the period up to 2050 [1]. | 4 |
| 2.1 | Tube feeding and spoon feeding method | 12 |
| 2.2 | Spoon approaching modes | 13 |
| 2.3 | Foods storage methods used in meal assistance robots | 14 |
| 2.4 | Different input signals used in meal assistance robots | 17 |
| 2.5 | Implanted electrodes over the motor cortex | 22 |
| 2.6 | Use of non invasive BMI to control a wheelchair | 23 |
| 2.7 | P300 wave. Figure from [2] | 25 |
| 2.8 | (a) Motor cortex. (b) Visual cortex | 26 |
| 3.1 | Hardware system overview of the meal assistance robot | 30 |
| 3.2 | Camera mounted of the end effector of the meal assistance robot . | 31 |
| 3.3 | Overall control algorithm of the system | 32 |
| 3.4 | 3D illustration of the meal assistance robot's path | 33 |
| 3.5 | Design of the meal assistance robot | 34 |
| 3.6 | Main components used in the fabrication process | 35 |

| | | |
|------|--|----|
| 3.7 | Workspace of the designed meal assistance robot | 36 |
| 3.8 | Quadrant design of the food storage method. | 36 |
| 3.9 | Kinematic analysis of the 4DOF robot arm | 37 |
| 3.10 | Forward kinematics analysis- figure 1 | 38 |
| 3.11 | Forward kinematics analysis- figure 2 | 39 |
| 3.12 | Inverse kinematics analysis- figure 1 | 39 |
| 3.13 | Inverse kinematics analysis- figure 2 | 40 |
| 3.14 | Feeder robot control algorithm | 41 |
| 3.15 | Connection diagram of electrical components | 43 |
| 4.1 | Section 1 of the main control algorithm | 45 |
| 4.2 | FFT analysis of Subject A and B during resting state | 46 |
| 4.3 | LED Panel connection diagram | 47 |
| 4.4 | 3mm Diameter 8 x 8 LED Matrix | 48 |
| 4.5 | OpenBCI EEG acquisition system | 49 |
| 4.6 | Electrode locations used according to 10/10 system | 50 |
| 4.7 | Ten20 electrode paste on gold cup electrodes | 51 |
| 4.8 | Goldcup Electrodes attached to a user's scalp using the EasyCap placement cap | 51 |
| 4.9 | Data preprocessing algorithm | 52 |
| 4.10 | Use of Moving window in data processing | 53 |

| | | |
|------|--|----|
| 4.11 | 6Hz classification instance | 54 |
| 4.12 | Overview of CCA based classification | 56 |
| 4.13 | CCA correlation values for user gazing. | 57 |
| 5.1 | Section 2 and 3 of the main control algorithm | 60 |
| 5.2 | Notations and motion directions of meal assistance robot designed in the proposed camera based automatic mouth position tacking method | 61 |
| 5.3 | Identification of user mouth open/close status | 64 |
| 6.1 | Experiment setup | 65 |
| 6.2 | Steps followed in one feeding cycle | 66 |
| 6.3 | Feedback form given to the experiment participants | 67 |
| 6.4 | FFT plots of 6,7 and 8Hz visual stimulus for the subject CJ | 68 |
| 6.5 | Canonical Correlation values of 6, 7 and 8Hz stimuli | 69 |
| 6.6 | Confusion matrices for each subject. | 72 |
| 6.7 | Average classification times for each subject at each frequency . . | 73 |
| 6.8 | Mean and standard deviation of the classification time taken by each subject | 73 |
| 6.9 | Image sequence of mouth position tracking process | 75 |
| 6.10 | Results from the feedback form | 76 |

LIST OF TABLES

| | | |
|-----|--|----|
| 2.1 | Overview of meal assistance robots | 10 |
| 2.2 | Control methods of existing meal assistance robots. | 16 |
| 6.1 | Accuracy and average classification time using FFT based classification | 67 |
| 6.2 | Accuracy and average classification time using CCA based classification | 71 |
| 6.3 | Performance of the camera based mouth position tracking method and mouth open/close detection method | 74 |

LIST OF ABBREVIATIONS

FFT Fast Fourier Transformation

CCA Canonical Correlation Analysis

ADL Activities of Daily Living

SSVEP Steady State Visually Evoked Potential

EEG Electroencephalography

FMRI Functional Magnetic Resonance Imaging

MRI Magnetic Resonance Imaging

DOF Degree of Freedom

SCI Spinal Cord Injury

TMR Targeted Muscle Reinnervation

ECoG Electrocorticography

EMG Electromyography

EOG Electrooculography

BMI Brain Machine Interface

fNIRS Functional Near-Infrared Spectroscopy

SSVEP Steady State Auditory Evoked Potential

ERP Event Related Potential