# BUG ALGORITHM TO GUIDE WHEELCHAIR MOTION BASED ON OFFLINE ELECTRO-OCULOGRAPHY SIGNAL

ANWAR AHMED HUSSEIN AL-HADDAD

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

DECEMBER 2013

To my beloved father, mother, wife, son, and daughter.

# ACKNOWLEDGEMENT

First and foremost, I would like to thank supervisor, Associate Professor Dr. Rubita binti Sudirman for the precious guidance and advice. She inspired me greatly to work in this study. Besides, I would like to thank my co-supervisor Mr. Camallil Omar for his support and recommendation.

The author is so grateful and would like to express his gratefulness to Universiti Teknologi Malaysia (UTM) and Ministry of Higher Education Malaysia for supporting and funding this study. The appreciation also goes to the Biomedical Instrumentation and Electronics Research Group (BMIE) especially Dr. Norlaili Mat Safri and other members for their advices to improve this study.

I would also like to take this opportunity to thank my research assistances, Muhammad Rashid bin Jimin and Koo Yin Hui for their help in the hardware and software of the wheelchair. Without them, it would be difficult for me to complete this research during the duration of the study.

Lastly, thanks to all my family members who gave me the support and the encouragement throughout the study.

## ABSTRACT

Certain disabled persons are not able to control the common powered wheelchair using joystick due to their limb movement restrictions. Hence, lots of current researches have studied other alternatives to control the powered wheelchair. Electrooculography (EOG) eye tracking control is one of the most ordinary alternative means to control the wheelchair because it offers a more natural mode to guide the wheelchair. Yet, it cannot be realized because users are normally not allowed to look around the surrounding environment during wheelchair motion. This is because the eye movements control the wheelchair while the user needs to look up to move forward, right to turn right, left to turn left and down to stop the wheelchair. In addition, this method exhausts the user due to the concentration needed during the navigation process. In this study, an automatic navigation approach alongside the manual method is proposed to guide the wheelchair by means of offline EOG signal. The automatic mode navigates the wheelchair from initial point to goal point while avoiding obstacles by employing Bug2 algorithm. Bug algorithms guide the robot from its starting point towards a preset goal point and avoid obstacles detected by sensors, and they do not require any other information about the environment in the navigation process. The EOG signals are measured, recorded, and analyzed using a biomedical measurement system (KL-720). The desired goal point direction and distance are calculated by analyzing horizontal and vertical gaze angles obtained. The hardware of the powered wheelchair is developed and modified so that it can be controlled automatically using EOG signal. The simulation done showed that Bug algorithms are able to guide the wheelchair to the desired destination based on only EOG signal. The new technique allows the user to look around without restraints, while the wheelchair is navigated automatically to the desired goal point.

## ABSTRAK

Orang-orang kurang upaya yang tertentu tidak dapat mengawal kerusi roda berkuasa biasa menggunakan kayu bedik kerana kekangan pergerakan anggota badan mereka. Oleh itu, banyak kajian semasa telah mengkaji alternatif lain untuk mengawal kerusi roda berkuasa. *Electrooculography* (EOG) mata kawalan pengesanan adalah salah satu kaedah alternatif yang paling biasa untuk mengawal kerusi roda kerana ia menawarkan cara yang lebih semulajadi untuk mengawal kerusi roda. Namun, ia tidak boleh dicapai kerana pengguna biasanya tidak dibenarkan melihat persekitaran semasa gerakan kerusi roda. Ini adalah kerana pergerakan mata mengawal kerusi roda ketika pengguna perlu mencari untuk bergerak ke hadapan, kanan untuk belok kanan, kiri untuk belok kiri, dan ke bawah untuk menghentikan kerusi roda. Di samping itu, kaedah ini meletihkan pengguna disebabkan oleh konsentrasi yang diperlukan semasa proses navigasi. Dalam kajian ini, pendekatan navigasi automatik di samping kaedah manual dicadangkan untuk mengawal kerusi roda dengan cara isyarat EOG secara tidak atas talian. Mod automatik melayari kerusi roda dari titik awal ke titik matlamat dengan mengelak halangan menggunakan Bug2 algoritma. Algoritma-algoritma Bug membimbing robot dari titik permulaan ke arah satu titik matlamat pratetap dengan mengelak halangan dikesan oleh sensor, dan mereka tidak memerlukan apa-apa maklumat lain mengenai keadaan sekeliling dalam proses navigasi. Isyarat EOG diukur, direkodkan dan dianalisis dengan menggunakan sistem pengukuran bioperubatan (KL-720). Arah matlamat yang dikehendaki dan jarak dikira dengan menganalisa sudut-sudut pandangan yang diperolehi. Secara mendatar dan menegak. Perkakasan kerusi roda berkuasa dibangunkan dan diubahsuai agar ia dapat dikawal secara automatik menggunakan isyarat EOG. Simulasi yang telah dilakukan menunjukkan bahawa algoritma Bug dapat mengawal kerusi roda ke destinasi yang dikehendaki hanya berdasarkan isyarat EOG. Teknik baru ini membolehkan pengguna melihat sekeliling tanpa sekatan, manakala kerusi roda bergerak secara automatik ke titik matlamat yang dikehendaki.

# TABLE OF CONTENTS


| CHAPTER | TITLE | PAGE |
|---|---|---|
| | **DECLARATION** | ii |
| | **DEDICATION** | iii |
| | **ACKNOWLEDGEMENT** | iv |
| | **ABSTRACT** | v |
| | **ABSTRAK** | vi |
| | **TABLE OF CONTENTS** | vii |
| | **LIST OF TABLES** | x |
| | **LIST OF FIGURES** | xi |
| | **LIST OF APPENDICES** | xv |
| | **LIST OF ABBREVIATIONS** | xvi |
| **1** | **INTRODUCTION** | 1 |
| | 1.1 Project Background | 1 |
| | 1.2 Problem Statement | 2 |
| | 1.3 Objectives | 2 |
| | 1.4 Scopes of Study | 2 |
| | 1.5 Project Significance | 3 |
| | 1.6 Thesis Organization | 4 |
| **2** | **LITERATURE REVIEW** | 5 |
| | 2.1 Introduction | 5 |
| | 2.2 Powered Wheelchair | 5 |
| | 2.2.1 Automatic Wheelchair Sensory | 6 |
| | 2.2.2 Powered Wheelchair Motion Guide Approaches | 10 |
| | 2.2.2.1 Joysticks Based | 10 |
| | 2.2.2.2 Sip and Puff Based | 11 |
| | 2.2.2.3 Voice Based | 12 |

2.2.2.4 Vision and Head Gesture Based 12
2.2.2.5 EEG Based 13
2.2.2.6 EMG and EOG Based 15
2.3 Electrooculography (EOG) 16
2.3.1 Anatomy and Physiology of Human Eyes 17
2.3.2 Configuration and Muscles Physiology of Human Eyes 18
2.3.3 Movement Properties of Human Eyes 19
2.3.4 Eye Movement Signal Potentials 19
2.3.5 Electrooculography Signal Recording 21
2.4 Path Finding Algorithms 23
2.4.1 Dijkstra's Algorithm 23
2.4.2 Heuristic Search Algorithms 24
2.4.3 Bug Algorithms 25
2.4.3.1 Bug2 Algorithm 27
2.4.3.2 Tangent-Bug Algorithm 28
2.5 Summary 32

**3 METHODOLOGY** 33
3.1 Study Planning 33
3.2 EOG Signal Measurement System 35
3.2.1 Tools and Experimental Setting 35
3.2.2 Experimental Setup for EOG Signal Measurement 37
3.2.3 EOG Signal Process and Analysis 42
3.3 Goal Point Distance and Position Measurements 43
3.4 The Wheelchair Hardware 48
3.4.1 Arduino Uno Board 48
3.4.2 Motor Driver 49
3.4.3 Sensor 51
3.4.4 Rotary Encoder 54
3.5 Software Developments and Implementations 56
3.5.1 Design of Initial Turning Direction 58
3.5.2 Sensors Control 59

3.5.3 Motors Control 60
3.5.4 Rotary Encoder Control 61
3.5.5 Bug2 Programming 63
3.5.6 Tangent-Bug Programming 64
3.6 Summary 66

**4 RESULT AND DISCUSSION** 67
4.1 Measurement of EOG signal 67
4.2 Tangent-Bug and Bug2 Algorithms Simulation and Comparison 73
4.3 System Software Calibrations 77
4.3.1 Turning Direction Based on Gaze Angle 77
4.3.2 Reading Distance from IR Sensors 78
4.3.3 Controlling Wheelchair Motor 79
4.3.4 Reading Pulse of Rotary Encoder to Calculate Travelled Distance 80
4.3.5 Wheelchair Motion Guide 81
4.4 Summary 85

**5 CONCLUSION AND RECOMMENDATION** 87
5.3 Conclusion 87
5.4 Recommendation for Future Work 88

**LIST OF PUBLICATIONS** 89

**REFERENCES** 91

Appendices A-F 101 - 172

# LIST OF TABLES


| TABLE NO. | TITLE | PAGE |
|---|---|---|
| 3.1 | List of connections from KL-72001 main unit to KL-75003 EOG module | 37 |
| 3.2 | Change of *d* values based on the change of β and α values, at fixed *h* = 150 cm | 46 |
| 3.3 | α threshold values | 47 |
| 3.4 | *β* threshold values | 48 |
| 3.5 | Motor driver input values to control speed and direction | 61 |
| 4.1 | Result of wheel rotation and wheelchair movement | 79 |

## LIST OF FIGURES


| FIGURE NO. | TITLE | PAGE |
|---|---|---|
| 2.1 | The Wheelesley wheelchair | 7 |
| 2.2 | Sensors placement of Wheelesley | 7 |
| 2.3 | Robotic wheelchair with sensor configuration | 8 |
| 2.4 | SENA wheelchair | 8 |
| 2.5 | Ghost echo problem with sonar sensor | 9 |
| 2.6 | Wheelchair joystick controls (a) Common joystick (b) Finger control (c) Touchpad drive control (d) Board with buttons control | 10 |
| 2.7 | Wheelchair Specialty Controls: (a) Chin-control, (b) Head Control | 11 |
| 2.8 | Sip-and-Puff wheelchair control method | 11 |
| 2.9 | Vision based wheelchair control | 13 |
| 2.10 | Wheelchair control based on EEG signal | 14 |
| 2.11 | HCI system input screen interface | 16 |
| 2.12 | Anatomy and parts of the human eye | 17 |
| 2.13 | The muscle physiology of the eye | 18 |
| 2.14 | Signal of eye movement potentials ; i) Downward eye movement, ii) Upward eye movement, iii) Leftward eye movement and iv) Rightward eye movement (Connell, 2007). | 20 |
| 2.15 | EOG electrode placement on the subject face | 21 |
| 2.16 | EOG horizontal signal produced from eye movement with different angles (Kherlopian *et al.*, 2006) | 22 |
| 2.17 | Gaze angle representation in the EOG measurement system | 22 |
| 2.18 | Blink detection by the EOG measurement system | 23 |

| | | |
|---|---|---|
| 2.19 | Dijkstra's algorithm: notice that all nodes are visited in terms to find the shortest path | 24 |
| 2.20 | A close-up of a path planned using Field D* showing individual grid cells, (Ferguson and Stentz, 2005) | 25 |
| 2.21 | M-line representation | 27 |
| 2.22 | Navigation process based on Bug2 algorithm | 28 |
| 2.23 | Illustration of robot equipped with range sensor concept | 29 |
| 2.24 | Navigation process based on Tangent-Bug algorithm | 29 |
| 2.25 | Paths for Bug algorithms on setting (A) | 30 |
| 2.26 | Paths for Bug algorithms in setting (B) | 31 |
| 3.1 | Flow chart of the study | 34 |
| 3.2 | KL-720 biomedical measurement system | 35 |
| 3.3 | Block diagram of EOG acquisition and processing | 36 |
| 3.4 | KL-75003 EOG module connection with KL-72001 main unit | 38 |
| 3.5 | (a) Disposable EOG electrode with Ag/AgCl, (b) Electrodes, (c) KL-79101 5-Conductor Electrode Cable | 39 |
| 3.6 | Electrode placements | 40 |
| 3.7 | Oscilloscope showing EOG signal measurements | 40 |
| 3.8 | The subject at an exact distance (d) from the wall with the arrangement for the EOG recording system, which demonstrates five points of view | 41 |
| 3.9 | The subject at an exact distance (*d*) from the wall with the arrangement for the EOG recording system, which demonstrates gaze angle points | 41 |
| 3.10 | EOG measurement experimental setup | 42 |
| 3.11 | Goal point angle measurement (Side view) | 43 |
| 3.12 | Goal point distance measurement (Top view) | 44 |
| 3.13 | Available goal points to be targeted by the user | 45 |
| 3.14 | Arduino Uno board | 49 |
| 3.15 | MD30B motor driver | 50 |

| | | |
|---|---|---|
| 3.16 | Motor driver interface with Arduino Uno | 51 |
| 3.17 | Block diagram of IR sensor | 52 |
| 3.18 | GP2Y0A21YK0F Sharp IR sensor | 52 |
| 3.19 | IR sensor interface with Arduino Uno | 53 |
| 3.20 | IR Sensor holder on the wheelchair | 53 |
| 3.21 | Mouse rotary encoder | 54 |
| 3.22 | Encoder interface with Arduino Uno | 55 |
| 3.23 | Rotary encoder and its holder | 55 |
| 3.24 | Flow chart diagram for controlling the wheelchair based on EOG signal | 56 |
| 3.25 | Outline of the wheelchair inputs and outputs | 57 |
| 3.26 | Work flow chart of the project | 58 |
| 3.27 | Graph of output voltage to distance of reflective object | 59 |
| 3.28 | Position of crossing IR sensors at the wheelchair | 60 |
| 3.29 | Pulse width modulation signal | 60 |
| 3.30 | Rotary encoder and roller configuration at wheelchair | 62 |
| 3.31 | Shaft is rotating clockwise | 62 |
| 3.32 | Shaft is rotating counter clockwise | 63 |
| 3.33 | Navigation behavior in Bug2 algorithm | 63 |
| 3.34 | Navigation behavior in Bug2 algorithm | 65 |
| 4.1 | EOG output waveform of center-rest point (C) | 68 |
| 4.2 | EOG output waveform of blink (B) | 68 |
| 4.3 | EOG output waveform of upward eye movement (U) | 69 |
| 4.4 | EOG output waveform of downward eye movement (D) | 69 |
| 4.5 | EOG output waveform of leftward eye movement (L) | 70 |
| 4.6 | EOG output waveform of rightward eye movement (R) | 71 |
| 4.7 | EOG output waveform of −10 ° horizontal gaze angle | 71 |
| 4.8 | EOG output waveform of −20 ° horizontal gaze angle | 72 |

| | | |
|---|---|---|
| 4.9 | EOG output waveform of −30 º horizontal gaze angle | 72 |
| 4.10 | EOG output waveform of −40 º horizontal gaze angle | 72 |
| 4.11 | Virtual map and navigation process (case A) | 74 |
| 4.12 | Virtual map and navigation process (case B) | 74 |
| 4.13 | Virtual map and navigation process (case C) | 75 |
| 4.14 | Bug2 algorithm simulation (tactile sensor) | 75 |
| 4.15 | Tangent-Bug algorithm simulation (range sensor) | 76 |
| 4.16 | Initial State before the program is executed, all LEDs are off | 77 |
| 4.17 | “Left” red LED turns on when α = −20 º | 77 |
| 4.18 | “Forward” yellow LED turns on when α = 0 º | 78 |
| 4.19 | “Right” green LED turns on when α = 20 º | 78 |
| 4.20 | (a) Two green LEDs switch on when no obstacle detected within 35 cm, (b) An obstacle detected less than 35 cm by left sensor, (c) An obstacle detected within 35 cm by right sensor | 79 |
| 4.21 | Serial monitor of Arduino Uno boot loader | 80 |
| 4.22 | Wheelchair motion | 81 |
| 4.23 | The wheelchair moves forward from initial state | 82 |
| 4.24 | The IR sensors sense obstacle within the range. Wheelchair stops and boundary following behavior is triggered | 82 |
| 4.25 | After sensing an obstacle, the wheelchair turns left to avoid the obstacle | 82 |
| 4.26 | The wheelchair stops when obstacle is no longer detected | 83 |
| 4.27 | The wheelchair turns right to follow the boundary of the obstacle | 83 |
| 4.28 | The wheelchair begins to turn right | 83 |
| 4.29 | The wheelchair detects the obstacle again and avoids it | 84 |
| 4.30 | Wheelchair meets the M-line again and starts to follow the path | 84 |
| 4.31 | The wheelchair reaches the goal point then stops | 84 |
| 4.32 | 60 º detection area | 85 |

# LIST OF APPENDICES


| APPENDIX | TITLE | PAGE |
|---|---|---|
| A | KL-720 biomedical measurement system | 101 |
| B | Arduino UNO microcontroller data sheet | 114 |
| C | Enhanced motor driver (MD30B) data sheet | 116 |
| D | Sharp IR GP2Y0A02YK0F range sensor data sheet | 120 |
| E1 | Programming code of initial turning direction based on eye gaze angle | 122 |
| E2 | Programming code of reading signal from IR sensor | 125 |
| E3 | Programming code of controlling motors | 129 |
| E4 | Programming code of reading pulse signal from rotary encoder | 131 |
| E5 | The complete navigation programming code for Bug2 | 132 |
| F | The Complete MATLAB Code for Tangent-Bug | 140 |

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| NFIC | - | New Freedom Initiative Act |
| ALS | - | Amyotrophic Lateral Sclerosis |
| EMG | - | Electromyography |
| EOG | - | Electrooculography |
| EPW | - | electric-powered wheelchair |
| IR | - | Infrared |
| EEG | - | Electroencephalography |
| BCI | - | brain-computer interfaces |
| HCI | - | Human Computer Interfaces |
| ECG | - | Electrocardiogram |
| ERG | - | Electroretinogram |
| CSV | - | Comma Separated Values |
| GUI | - | graphical user interface |
| PWM | - | pulse-width modulations |
| USB | - | Universal Serial Bus |
| CW | - | clockwise rotation |
| CCW | - | counterclockwise rotation |
| GND | - | Ground |
| IRED | - | Infrared Emitting Diode |
| PSD | - | Position Sensitive Detector |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

The New Freedom Initiative Act (NFIC) approximated that, aged and disabled individuals whom necessitate for wheelchair are more than 100 million global. The common powered wheelchairs; that are guided using joystick, are not handy for the disabled with limb movement restrictions such as spinal cord injury and amyotrophic lateral sclerosis (ALS). Hence, an alternative approaches are investigated to help those disabled and elderly who cannot use the manual powered wheelchair. These alternative approaches concentrated on guiding the wheelchair by means of other body signals and other body parts that are not defected.

Among the guiding approach substitutes are: controlling a wheelchair by means of head gestures suggested by Wei (2004), (Matsumotot *et al.*, 2001), Nakanishi *et al.* (1999) and Kuno *et al.* (2001); guiding by means of voice recognition by (Levine *et al.*, 1999; Cagigas and Abascal, 2004); a guide based on the Electromyography (EMG) signal proposed by Felzer and Freisleben (2002) and Moon *et al.* (2005); and Electrooculography (EOG) eye tracking control presented in the literature by Mazo (2001).

## 1.2 Problem Statement

The EOG eye tracking guide presents a more likely and natural manner to control the wheelchair. Still, it is neglected, for the reason that the wheelchair user is not capable to look or gaze at the nearby atmosphere throughout the navigation route, which is very exhausting for the user's eyes. Hence, several researchers such as Hashimoto *et al.* (2009) and Tsui *et al.* (2008) attempted to rise above this difficulty by utilizing the EMG signal, which control direction; in addition to the EOG signal, which control speed to guide the wheelchair. In this research, the powered wheelchair is guided by means of eye gazes and blinks. Bug algorithm is utilized to navigate the wheelchair automatically to the desired goal point.

## 1.3 Objectives

This study aims to assist those people with serious disabilities to advance their mobility and substantially enhance their living quality. The main objective of this study is to guide the wheelchair motion based on EOG signal. Yet, the wheelchair user will be able to look around and surround, due to the hands-free control system that uses only eyes gaze and blinks to control the powered wheelchair. For this to be achieved, the following objectives need to be attained:

1. Develop powered wheelchair hardware and software, which can be controlled based on EOG signal.

2. Record, and analyze eye movements by means of the EOG signal measurement system.

## 1.4 Scopes of Study

A wheelchair motion guide based on EOG signal is a recent study topic. EOG offers a lot of possibilities and functions beside the wheelchair motion guide is a promising research area. The scope of this study contains:

1. Review on powered wheelchairs and approaches used to control them, including EOG signal which is applied in this study. The EOG signal used in this research is offline signal.

2. Study and compare path finding algorithms including Bug algorithms, which are implemented in our project. Bug2 and Tangent-Bug are simulated, and the wheelchair is guided automatically by means of Bug2 algorithm.

3. Development of the automatic wheelchair's hardware, and software. Hardware includes sensors, motor drivers, rotary encoder, microcontroller, and the interface among these parts with the wheelchair. While software includes programming the microcontroller to read all inputs and also to utilize the Bug algorithm.

4. Investigate the eye movement tracking and recording based on the EOG signal measurement system. Also, utilize the gaze angles and blinks measured to control the wheelchair automatically and manually.

## 1.5 Project Significance

A new automatic controlling method is introduced beside the common manual method. In the automatic controlling mode, the user gazes at the desired destination, then blink to send the signal to the wheelchair to start navigating. Bug2 algorithm is utilized to control the wheelchair in automatic guide mode.

This work is conducted especially to rise above the drawback of the typical powered wheelchair controlled based on EOG signal. The user can enjoy looking at the neighboring environment freely during the wheelchair motion process.

## 1.6 Thesis Organization

After acknowledging the requirement to fulfill the perception of this study, this thesis has been written and accumulated with the optimum effort in terms to attain the ease of the reader. This report includes six chapters with the brief outline of each chapter as stated as follows:

Chapter 1 serves as an introduction to this research; it includes the background of the project, problem statements, objectives of the research, and scopes of the study.

After that, Chapter 2 provides literature reviews from previous research work from other researches on powered wheelchair motion guides, path finding algorithms and EOG signal.

And Chapter 3 has been utilized to explain and discusses the methodology applied in this project, including the project planning and measurements of EOG signal ; the hardware, and software of the wheelchair; as well as calibration and development of the controlling method based on Bug2 algorithm.

In Chapter 4, the findings and simulation of this project are demonstrated and examined together with the indication to strengthen the results of the study.

The last chapter, particularly Chapter 5 ceases the entire contents of this thesis and provides the conclusions and recommendations on researches that may be directed at the time ahead.

## REFERENCES


Allison, B. Z., Wolpaw, E. W. & Wolpaw, J. R. (2007). Brain-Computer Interface Systems: Progress and Prospects. *Journal of Expert Review of Medical Devices,* 4**,** 463-474.

Aylor, J., Ramey, R., Schaddegg, J. & Reger, S. (1979). Versatile Wheelchair Control System. *Journal of Medical and Biological Engineering,* 17**,** 110-114.

Barea, R., Boquete, L., Mazo, M. & Lopez, E. (2002a). System for Assisted Mobility Using Eye Movements Based on Electrooculography. *Journal of IEEE Transactions on Neural Systems and Rehabilitation,* 10**,** 209-218.

Barea, R., Boquete, L., Mazo, M. & Lopez, E. (2002b). Wheelchair Guidance Strategies Using Eog. *Journal of Intelligent & Robotic Systems,* 34**,** 279-299.

Barea, R., Boquete, L., Ortega, S., López, E. & Rodríguez-Ascariz, J. (2012). Eog-Based Eye Movements Codification for Human Computer Interaction. *Expert Systems with Applications,* 39**,** 2677-2683.

Belov, D. P., Eram, S. Y., Kolodyazhnyi, S. F., Kanunikov, I. E. & Getmanenko, O. V. (2010). Electrooculogram Detection of Eye Movements on Gaze Displacement. *Neurosci Behav Physiol,* 40**,** 583-91.

Bergasa, L. M., Mazo, M., Gardel, A., Garcia, J. C., Ortuno, A. & Mendez, A. E. (1999). Guidance of a Wheelchair for Handicapped People by Face Tracking. *IEEE Symposium on Emerging Technologies and Factory Automation*. 105-111.

Bergasa, L. M., Mazo, M., Gardel, A., Barea, R. & Boquete, L. (2000). Commands Generation by Face Movements Applied to the Guidance of a Wheelchair for Handicapped People. *Proceedings of International Conference on Pattern Recognition,* 15**,** 660-663.

Blankertz, B., Muller, K. R., Curio, G., Vaughan, T. M., Schalk, G., Wolpaw, J. R., Schlogl, A., Neuper, C., Pfurtscheller, G., Hinterberger, T., Schroder, M. & Birbaumer, N. (2004). The Bci Competition 2003: Progress and Perspectives

in Detection and Discrimination of Eeg Single Trials. *Journal of IEEE Transactions on Biomedical Engineering,* 51**,** 1044-1051.

Blankertz, B., Dornhege, G., Krauledat, M., Schröder, M., Williamson, J., Murray-Smith, R. & Müller, K. R. (2006). The Berlin Brain-Computer Interface Presents the Novel Mental Typewriter Hex-O-Spell. *Proceedings of the 3rd International Brain-Computer Interface Workshop and Training Course, Graz, Australia,* 14**,** 147-152.

Bley, F., Rous, M., Canzler, U. & Kraiss, K. F. (2004). Supervised Navigation and Manipulation for Impaired Wheelchair Users. *IEEE International Conference on Systems, Man and Cybernetics*. 3**,** 2790-2796.

Bolt, R. A. (1990). A Gaze-Responsive Self-Disclosing Display. *Proceedings of the SIGCHI conference on Human factors in computing systems: Empowering people*. *Association for Computing Machinery Digital Library,* 3-10.

Bourke, T. (2001). *Development of a Robotic Wheelchair*. PhD, University of Wollongong.

Buniyamin, N., Wan Ngah, W., Sariff, N. & Mohamad, Z. (2011). A Simple Local Path Planning Algorithm for Autonomous Mobile Robots. *International Journal of Systems Applications, Engineering & Development,* 5**,** 151-159.

Cagigas, D. & Abascal, J. (2004). Hierarchical Path Search with Partial Materialization of Costs for a Smart Wheelchair. *Journal of Intelligent & Robotic Systems,* 39**,** 409-431.

Carr, J. J. & Brown, J. M. (2001). *Introduction to Biomedical Equipment Technology*, (4th ed.) Prentice Hall New Jersey.

Carrino F., D. J., Mugellini E., Khaled O. A., and Ingold R. (2012). A Self-Paced Bci System to Control an Electric Wheelchair: Evaluation of a Commercial, Low-Cost Eeg Device. *Biosignals and Biorobotics Conference***,** 1-6.

Connell, G. G. (2007). Cursor Control Using Eeg Signals from Eye Movement Potentials. *Suresnes, France: Les Laboratories Sevier Edition*.

Craig, D. A. & Nguyen, H. T. (2006). Wireless Real-Time Head Movement System Using a Personal Digital Assistant (Pda) for Control of a Power Wheelchair. *27th IEEE Annual International Conference of the Engineering in Medicine and Biology Society*. 772-775.

Çulha, U. (n.d.). *Bilkent University*. Available: http://www.cs.bilkent.edu.tr/~culha/cs548/hw1/ [Accessed 11 March 2011].

Davson, H. (1976). The Physiology of the Eye. *Academic Press, New York***,** 86–111.

Deng, L. Y., Hsu, C. L., Lin, T. C., Tuan, J. S. & Chang, S. M. (2010). Eog-Based Human-Computer Interface System Development. *Expert Systems with Applications,* 37**,** 3337-3343.

Dijkstra, E. W. (1959). A Note on Two Problems in Connexion with Graphs. *Numerische Mathematik,* 1**,** 269-271.

Donchin, E., Spencer, K. M. & Wijesinghe, R. (2000). The Mental Prosthesis: Assessing the Speed of a P300-Based Brain-Computer Interface. *Journal of IEEE Transactions on Rehabilitation Engineering* 8**,** 174-9.

Felzer, T. & Freisleben, B. (2002). Hawcos: The "Hands-Free" Wheelchair Control System. *Proceedings of the 5th international ACM Conference on Assistive technologies*. 127-134.

Felzer, T., Strah, B., Nordmann, R. & Miglietta, S. (2009). Alternative Wheelchair Control Involving Intentional Muscle Contractions. *International Journal on Artificial Intelligence Tools,* 18**,** 439-465.

Ferguson, D. & Stentz, A. (2005). The Field D* Algorithm for Improved Path Planning and Replanning in Uniform and Non-Uniform Cost Environments. *Robotics Institute, Technical Report CMU-RI-TR-05-19, Carnegie Mellon School of Computer Science***,** 05-19.

Galán, F., Nuttin, M., Lew, E., Ferrez, P. W., Vanacker, G., Philips, J. & Millán, J. R. (2008). A Brain-Actuated Wheelchair: Asynchronous and Non-Invasive Brain–Computer Interfaces for Continuous Control of Robots. *Clinical Neurophysiology,* 119**,** 2159-2169.

Gips, J., Olivieri, P. & Tecce, J. (1993). Direct Control of the Computer through Electrodes Placed around the Eyes. *Human-Computer Interaction: Applications and Case Studies***,** 630-635.

Goncharova, Ii, Mcfarland, D. J., Vaughan, T. M. & Wolpaw, J. R. (2003). Emg Contamination of Eeg: Spectral and Topographical Characteristics. *Journal of the International Federation of Clinical Neurophysiology,* 114**,** 1580-93.

Gonzalez, J., Muæoz, A. J., Galindo, C., Fernandez-Madrigal, J. A. & Blanco, J. L. (2006). A Description of the Sena Robotic Wheelchair. *IEEE Mediterranean Electrotechnical Conference*. 437-440.

Goo, J., Suh, D., Cho, H., Park, K. & Hahn, M. (2005). Poster Proposal: A Bci Based Virtual Control Testbed for Motion Disabled People. *Proceedings of the International Conference on Augmented Tele-Existence*. 283.

Guger, C., Holzner, C., Grönegress, C., Edlinger, G. & Slater, M. (2008). Control of a Smart Home with a Brain-Computer Interface. *Proceedings of the 4th International Brain–Computer Interface Workshop and Training Course*. 18-21.

Guger, C., Daban, S., Sellers, E., Holzner, C., Krausz, G., Carabalona, R., Gramatica, F. & Edlinger, G. (2009). How Many People Are Able to Control a P300-Based Brain-Computer Interface (Bci)? *Journal of Neuroscience Letters* 462**,** 94-98.

Han, J. S., Zenn Bien, Z., Kim, D. J., Lee, H. E. & Kim, J. S. (2003). Human-Machine Interface for Wheelchair Control with Emg and Its Evaluation. *Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. 1602-1605.

Haro, F. & Torres, M. (2006). A Comparison of Path Planning Algorithms for Omni-Directional Robots in Dynamic Environments. *IEEE 3rd Latin American Robotics Symposium*. 18-25.

Hashimoto, M., Takahashi, K. & Shimada, M. (2009). Wheelchair Control Using an Eog- and Emg-Based Gesture Interface. *IEEE/ASME International Conference on Advanced Intelligent Mechatronics*. 1212-1217.

Hutchinson, T. E., White Jr, K. P., Martin, W. N., Reichert, K. C. & Frey, L. A. (1989). Human-Computer Interaction Using Eye-Gaze Input. *IEEE Transactions on Systems, Man and Cybernetics,* 19**,** 1527-1534.

Jacob, R. J. K. (1991). The Use of Eye-Movements in Human-Computer Interaction Techniques - What You Look at Is What You Get. *ACM Transactions on Information Systems,* 9**,** 152-169.

Jagla, F., Jergelova, M. & Riecansky, I. (2007). Saccadic Eye Movement Related Potentials. *Journal of Physiological Research,* 56**,** 707-13.

Jia, P., Hu, H. S. H., Lu, T. & Yuan, K. (2007). Head Gesture Recognition for Hands-Free Control of an Intelligent Wheelchair. *Industrial Robot: an International Journal,* 34**,** 60-68.

Kamon, I. & Rivlin, E. (1997). Sensory-Based Motion Planning with Global Proofs. *IEEE Transactions on Robotics and Automation,* 13**,** 814-822.

Kamon, I., Rimon, E. & Rivlin, E. (1998). Tangentbug: A Range-Sensor-Based Navigation Algorithm. *International Journal of Robotics Research,* 17**,** 934-953.

Kang, S. P. & Katupitiya, J. (2004). A Hand Gesture Controlled Semi-Autonomous Wheelchair. *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*. 3565-3570.

Kherlopian, A. R., Gerrein, J. P., Yue, M., Kim, K. E., Kim, J. W., Sukumaran, M. & Sajda, P. (2006). Electrooculogram Based System for Computer Control Using a Multiple Feature Classification Model. *28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. 1295-1298.

Koenig, S. & Likhachev, M. (2002). Improved Fast Replanning for Robot Navigation in Unknown Terrain. *Proceedings of IEEE International Conference on Robotics and Automation*. 968-975.

Koenig, S., Likhachev, M. & Furcy, D. (2004). Lifelong Planning a*. *Artificial Intelligence,* 155**,** 93-146.

Koenig, S. & Likhachev, M. (2005). Fast Replanning for Navigation in Unknown Terrain. *IEEE Transactions on Robotics,* 21**,** 354-363.

Kuno, Y., Murashima, T., Shimada, N. & Shirai, Y. (2000). Interactive Gesture Interface for Intelligent Wheelchairs. *IEEE International Conference on Multimedia and Expo*. 789-792.

Kuno, Y., Murakami, Y. & Shimada, N. (2001). User and Social Interfaces by Observing Human Faces for Intelligent Wheelchairs. *Proceedings of the 2001 Workshop on Perceptive User Interfaces*. *ACM*, 1-4.

Latombe, J. C. (1991). *Robot Motion Planning*, (1st ed.) Kluwer Academic Publishers, Boston, MA.

Levine, S. P., Bell, D. A., Jaros, L. A., Simpson, R. C., Koren, Y. & Borenstein, J. (1999). The Navchair Assistive Wheelchair Navigation System. *Journal of IEEE Transactions on Rehabilitation Engineering* 7**,** 443-51.

Lew, E., Nuttin, M., Ferrez, P. W., Degeest, A., Buttfield, A., Vanacker, G. & Millán, J. R. (2006). Noninvasive Brain-Computer Interface for Mental Control of a Simulated Wheelchair. *Proceedings of the 3rd International Brain-Computer Interface Workshop & Training Course*.

Likhachev, M. & Koenig, S. (2002). Incremental Replanning for Mapping. *IEEE/RSJ International Conference on Intelligent Robots and Systems*. 667-672.

Lumelsky, V. & Skewis, T. (1990). Incorporating Range Sensing in the Robot Navigation Function. *IEEE Transactions on Systems Man and Cybernetics,* 20**,** 1058-1069.

Lumelsky, V. J. & Stepanov, A. A. (1986). Dynamic Path Planning for a Mobile Automaton with Limited Information on the Environment. *IEEE Transactions on Automatic Control,* AC-31**,** 1058-1063.

Lüth, T., Ojdanić, D., Friman, O., Prenzel, O. & Gräser, A. (2007). Low Level Control in a Semi-Autonomous Rehabilitation Robotic System Via a Brain-Computer Interface. *IEEE 10th International Conference on Rehabilitation Robotics*. 721-728.

Magid, E. & Rivlin, E. (2004). Cautiousbug: A Competitive Algorithm for Sensory-Based Robot Navigation. *Proceedings. 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2757-2762.

Magosso, E., Ursino, M., Zaniboni, A. & Gardella, E. (2009). A Wavelet-Based Energetic Approach for the Analysis of Biomedical Signals: Application to the Electroencephalogram and Electro-Oculogram. *Applied Mathematics and Computation,* 207**,** 42-62.

Main, A., Kelly, S. & Manley, G. (1997). The Treatment of a Severe Ataxic Dysarthria, Using Electropalatography. *Royal College of Speech & Language Therapists" Bulletin*.

Matsumotot, Y., Ino, T. & Ogsawara, T. (2001). Development of Intelligent Wheelchair System with Face and Gaze Based Interface. *Proceedings of the 10th IEEE International Workshop on Robot and Human Interactive Communication*. 262-267.

Mazo, M. (2001). An Integral System for Assisted Mobility. *IEEE Robotics and Automation Magazine,* 8**,** 46-56.

Mcfarland, D. J., Sarnacki, W. A., Vaughan, T. M. & Wolpaw, J. R. (2005). Brain-Computer Interface (Bci) Operation: Signal and Noise During Early Training Sessions. *Journal of Electroencephalography and Clinical Neurophysiology,* 116**,** 56-62.

Miller, G. E., Brown, T. E. & Randolph, W. R. (1985). Voice Controller for Wheelchairs. *Journal of Medical and Biological Engineering,* 23**,** 597-600.

Mitra, S. K. & Kuo, Y. (2006). *Digital Signal Processing: A Computer-Based Approach*, (1st ed.) McGraw-Hill New York.

Moon, I., Lee, M., Ryu, J. & Mun, M. (2003a). Intelligent Robotic Wheelchair with Emg-, Gesture-, and Voice-Based Interfaces. *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, Las Vegas, NV*. 3453-3458.

Moon, I., Kim, K., Ryu, J. & Mun, M. (2003b). Face Direction-Based Human-Computer Interface Using Image Observation and Emg Signal for the Disabled. *Proceedings of IEEE International Conference on Robotics and Automation*. 1515-1520.

Moon, I., Lee, M., Chu, J. & Mun, M. (2005). Wearable Emg-Based Hci for Electric-Powered Wheelchair Users with Motor Disabilities. *Proceedings of the IEEE International Conference on Robotics and Automation*. 2649-2654.

Muller-Putz, G. R. & Pfurtscheller, G. (2008). Control of an Electrical Prosthesis with an Ssvep-Based Bci. *Journal of IEEE Transactions on Biomedical Engineering* 55**,** 361-4.

Nakanishi, S., Kuno, Y., Shimada, N. & Shirai, Y. (1999). Robotic Wheelchair Based on Observations of Both User and Environment. *Proceedings of IEEE/RSJ International Conference on Intelligent Rbots and Systems*. 912-917.

Ng, J. & Braunl, T. (2007). Performance Comparison of Bug Navigation Algorithms. *Journal of Intelligent & Robotic Systems,* 50**,** 73-84.

Noborio, H. (1990). A Path-Planning Algorithm for Generation of an Intuitively Reasonable Path in an Uncertain 2d Workspace. *Proceedings of the Japan-USA Symposium on Flexible Automation*. 477-480.

Noborio, H., Maeda, Y. & Urakawa, K. (1999). Three or More Dimensional Sensor-Based Path-Planning Algorithm Hd - I. *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*. 1699-1706.

Noborio, H., Fujimura, K. & Horiuchi, Y. (2000). A Comparative Study of Sensor-Based Path-Planning Algorithms in an Unknown Maze. *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*. 909-916.

Noborio, H., Nogami, R. & Hirao, S. (2004). A New Sensor-Based Path-Planning Algorithm Whose Path Length Is Shorter on the Average. *Proceedings IEEE International Conference on Robotics and Automation*. 2832-2839.

Pačnik, G., Benkič, K. & Brečko, B. (2005). Voice Operated Intelligent Wheelchair - Voic. *Proceedings of the IEEE International Symposium on Industrial Electronics*. 1221-1226.

Pires, G. & Nunes, U. (2002). A Wheelchair Steered through Voice Commands and Assisted by a Reactive Fuzzy-Logic Controller. *Journal of Intelligent & Robotic Systems,* 34**,** 301-314.

Pynadath, D. V., Tan, H. Z. & Horowitz, D. M. (1993). A Study of the Information Capacity of Human Eye Movement for Augmentative Communication. *Proceedings of the RESNA*. 96-98.

Rebsamen, B., Burdet, E., Cuntai, G., Chee Leong, T., Qiang, Z., Ang, M. & Laugier, C. (2007). Controlling a Wheelchair Using a Bci with Low Information Transfer Rate. *IEEE 10th International Conference on Rehabilitation Robotics*. 1003-1008.

Robert S., H. M., Galley N., and Golz M. (15 Aug. 2011). Eogui – a Software to Analyze Electro-Oculogram (Eog) Recordings. Available: http://www.mathworks.com/matlabcentral/fileexchange/32493-eogui-a-software-to-analyze-electro-oculogram-eog-recordings [Accessed 27 Sept. 2011].

Rodieck, R. W. (1973). *The Vertebrate Retina: Principles of Structure and Function*, (1st ed.) W. H. Freeman, San Francisco.

Salojärvi, J., Puolamäki, K., Simola, J., Kovanen, L., Kojo, I. & Kaski, S. (2005). Inferring Relevance from Eye Movements: Feature Extraction. *Helsinki University of Technology, Publications in Computer and Information Science*.

Sankaranarayanan, A. & Vidyasagar, M. (1990a). A New Path Planning Algorithm for Moving a Point Object Amidst Unknown Obstacles in a Plane. *IEEE Conference on Robotics and Automation*. 1930-1936.

Sankaranarayanan, A. & Vidyasagar, M. (1990b). Path Planning for Moving a Point Object Admidst Unknown Obstacles in a Plane: A New Algorithm and a General Theory for Algorithm Development. *Proceedings of the IEEE International Conference on Robotics and Automation*. 1111-1119.

Simpson, R. C. & Levine, S. P. (2002). Voice Control of a Powered Wheelchair. *Journal of IEEE Transactions on Neural Systems and Rehabilitation,* 10**,** 122-5.

Simpson, R. C. (2005). Smart Wheelchairs: A Literature Review. *J Rehabil Res Dev,* 42**,** 423-36.

Stentz, A. (1994). Optimal and Efficient Path Planning for Partially-Known Environments. *Proceedings of IEEE International Conference on Robotics and Automation*. 3310-3317.

Tanaka, K., Matsunaga, K. & Wang, H. O. (2005). Electroencephalogram-Based Control of an Electric Wheelchair. *IEEE Transactions on Robotics,* 21**,** 762-766.

Trejo, L. J., Rosipal, R. & Matthews, B. (2006). Brain-Computer Interfaces for 1-D and 2-D Cursor Control: Designs Using Volitional Control of the Eeg Spectrum or Steady-State Visual Evoked Potentials. *Journal of Rehabilitation Research & Development,* 14**,** 225-9.

Tripathi, R. & Tripathi, B. (1984). Anatomy of the Human Eye, Orbit and Adnexa. *Journal of Vegetative physiology and Biochemistry,* 1**,** 1-268.

Tsui, C. S. L., Jia, P., Gan, J. Q., Hu, O. & Yuan, K. (2008). Emg-Based Hands-Free Wheelchair Control with Eog Attention Shift Detection. *IEEE International Conference on Robotics and Biomimetics*. 1266-1271.

Usakli, A., Gurkan, S., Aloise, F., Vecchiato, G. & Babiloni, F. (2009). On the Use of Electrooculogram for Efficient Human Computer Interfaces. *Jurnal of Computational Intelligence and Neuroscience***,** 135-629.

Venkataramanan, S., Prabhat, P., Choudhury, S. R., Nemade, H. B. & Sahambi, J. (2005). Biomedical Instrumentation Based on Electrooculogram (Eog) Signal Processing and Application to a Hospital Alarm System. *Proceedings of International Conference on Intelligent Sensing and Information Processing, 2005*. *IEEE*, 535-540.

Von Spreckelsen, S., Grumstup, P., Johnsen, J. & Hansen, L. K. (1994). Modeling of Glaucoma Induced Changes in the Retina and Neural Net Assisted Diagnosis. *Proceedings of the IEEE Workshop Neural Networks for Signal Processing*. 490-499.

Wei, Y. (2004). *Vision-Based Human-Robot Interaction and Navigation of Intelligent Service Robots.* PhD Thesis, Institute of Automation, Chinese Academy of Sciences, Beijing, China.

Wolpaw, J. R., Birbaumer, N., Mcfarland, D. J., Pfurtscheller, G. & Vaughan, T. M. (2002). Brain-Computer Interfaces for Communication and Control. *Journal of Electroencephalography and Clinical Neurophysiology,* 113**,** 767-91.

Yanco, H. A. (2000). *Shared User-Computer Control of a Robotic Wheelchair System.* PhD, Massachusetts Institute of Technology.

Yoda, I., Tanaka, J., Raytchev, B., Sakaue, K. & Inoue, T. (2006). Stereo Camera Based Non-Contact Non-Constraining Head Gesture Interface for Electric Wheelchairs. *18th International Conference on Pattern Recognition, 2006*. *IEEE,* 740-745.

Yoda, I., Sakaue, K. & Inoue, T. (2007). Development of Head Gesture Interface for Electric Wheelchair. *Proceedings of the 1st International Convention on Rehabilitation Engineering & Assistive Technology: in Conjunction with 1st Tan Tock Seng Hospital Neurorehabilitation Meeting*. *ACM,* 77-80.

Yufka, A. & Parlaktuna, O. (2009). Performance Comparison of Bug Algorithms for Mobile Robots. *Proceedings of the 5th International Advanced Technologies Symposium, Karabuk, Turkey*.

Zohaib M., P. M., Riaz R. A., Javaid N., Ilahi M., and Khan R. D. (2013). Control Strategies for Mobile Robot with Obstacle Avoidance. *Journal of Applied Sciences Research,* 3(4)**,** 1027-1036.