Preface

BACKGROUND AND MOTIVATION

Neuroprosthetics is a fast-growing area that brings together Biomedical Engineering and Neuroscience and seeks to interface the neural system directly to prostheses. The main goal is to restore motor, sensory, and cognitive functions. Neuroprosthetics is electrical stimulation technologies that replace or assist malfunctioned neuromuscular systems and attempt to restore normal body functions. These devices are either implanted or worn (like wristband or headband) on the body. Some of the examples include intramuscular stimulation system or implanted neuromuscular control.

Neuroprosthetics has several applications; for instance, one class of neuroprostheses helps restore movement to paralyzed patients. Neural prostheses use Electroencephalography (EEG) and Electromyography (EMG) interfaces to bypass dysfunctional pathways in the nervous system by applying electronics to replace lost function. For example, cochlear implants use electronics to detect and encode sound and then stimulate the auditory nerve to allow deaf individuals to hear. It has several applications. Some of the major ones include Brain-Computer Interface (BCI) for motor control, brain activity monitoring for epilepsy prediction, and proprioceptive feedback for upper-limb prosthetics. This book brings the current trends and applications of state-of-the-art of Neuroprosthetics research.

INTENDED READERSHIP

The goal of this edited manuscript is to bring together recent advances in Neuroprosthetics by combining research activities ranging from basic engineering discipline to applied sciences. It provides readers with a detailed introduction to Neuroprosthetics techniques and applications, while presenting several new results and ideas and further developments and explanation of existing algorithms.

The book presents several new results, concepts, and further developments in the area of Neuroprosthetics. It is essential reading for researchers and practitioners with an interest in Neuroprosthetics research. The book is likely to be of interest to graduate and postgraduate students, engineers and scientists in the field of Neuroprosthetics and Biomedical Engineering. This book can also be used as a handbook to students and professionals seeking to gain a better understanding of where Neuroprosthetics research stands today. We are honoured to be editing a book with such captivating and exciting content, written by a select group of talented researchers. We would like to thank all the authors, who have committed so much towards the publication of this work.
THE ORGANISATION OF CHAPTERS

The book is organized in two sections. In Section 1, “Neuroprosthetics Theory and Model,” basics of Neuroprosthetics theory and MUAP are shown in detail. Chapters of this section combine theory and hypothesis-driven experimentation with computer-based modelling and simulation to analyse neuroprosthetics applications.

Section 2, titled “Neuroprosthetics for BCI and Other Applications,” presents methods and Neuroprosthetics systems that provide insights on how these can be exploited further in real-world applications. Real world BCI applications, which are employed to evaluate the effectiveness of the neuroprosthetics-based systems, are also presented in detail. Below, an overview of the book chapters is presented.

Section 1: Neuroprosthetics Theory and Model

Chapter 1: Neurorprosthetics – Introduction

In this chapter, Ganesh Naik explains the recent advances and applications of neuroprosthetics. Neuroprostheses use electric stimuli to stimulate neural structures, muscles, or receptors in order to support, augment, or partly restore the respective disordered or lost function. The objective is to help the patient to participate in everyday life. The use of a neural prosthesis can improve the quality of life of the person concerned. The future of neuroprosthetics is challenging as well as interesting as it deals with several latest technological advancements that connect both biology and technology together.

Chapter 2: Retinal Prosthetics

In this chapter, Djilas and Picaud discuss neuroanatomical and current open issues of the retinal prosthetics, such as implant placement, biocompatibility, electrode design, and safety. They first briefly introduce the neuroanatomical basis for vision and explain how the retina processes visual information. Pathology of the retina and the conditions that cause photoreceptors degeneration and lead to blindness are then given, followed by the main part of the chapter in which authors present an overview of the concept of restoring vision with visual prosthetics. The focus is specifically on retinal prostheses and electrical stimulation parameters used with these devices. Both in vitro and in vivo animal studies from the last decade are surveyed, together with the latest results from human trials conducted in multiple research centres worldwide. In the final section, the authors give their opinion on the future development and perspectives of the retinal prosthetics research.
Chapter 3: Sensors for Motor Neuroprosthetics – Current Applications and Future Directions

In this chapter, Ambrosini, Bejarano, and Pedrocchi summarize the state of the art of sensors used in Functional Electrical Stimulation (FES) and motor neuroprostheses. Clinical applications of FES provide both functional and therapeutic benefits. To enhance the functionality of FES systems and to improve the control of the activated muscles through open-loop or feedback controllers, solutions to gather information about the status of the system in real time and to easily detect the intention of the subject have to be optimized. These sensors can be classified in two categories: sensors of biological signals and sensors of non-biological signals. Here, the authors report definitions, advantages, and disadvantages for each sensor and also explain guidelines to compare sensors for the design of motor neuroprostheses.

Chapter 4: Models of Cooperation between Medical Specialists and Biomedical Engineers in Neuroprosthetics

In this chapter, Mikołajewska and Mikołajewski answer the question, how can biomedical engineers be incorporated into research and clinical practice in neuroprosthetics considering the various factors, necessary changes in educational processes, ethical issues, and associated organizational problems? Current models of education and cooperation within interdisciplinary therapeutic teams only concern medical specialists. The development of novel technologies associated with neuroprosthetics and their clinical applications needs and interdisciplinary knowledge, including not only medical sciences, but IT, biomedical engineering, biocybernetics, and robotics. The variability of possible neurological deficits, interventions, and even scales—from nanotechnology up to rehabilitation robots and brain-computer-interface controlled exoskeletons as whole-body neuroprostheses—make this task very difficult.

Chapter 5: Are We the Robots? Man-Machine Integration

In this chapter, Pisotta and Ionta review the hurdles involved in making the Brain-Machine Interfaces (BMIs) a reality. Humans experience and interact with the world through their body. One of the most important features of the human is the interaction between mind and body. Since the original demonstration that electrical activity of the cortical neurons can be employed to directly control a robotic device, the research on the so-called BMIs has impressively grown. For example, current BMIs dedicated to both experimental and clinical studies can translate raw neuronal signals into computational commands to reproduce reaching or grasping in artificial actuators. These developments hold promise for the restoration of limb mobility in paralyzed individuals. Before this goal can be achieved, several hurdles have to be overcome, including developments in real-time computational algorithms and in designing fully implantable and biocompatible devices. Future investigations will have to address the best solutions for restoring sensation to the prosthetic limb, which still remains a major challenge to full integration of the limb into the user’s self-image.
Chapter 6: Neuroprostheses as an Element of an Eclectic Approach to Intervention in Neurorehabilitation

In this chapter, Mikołajewska investigates the extent to which the available opportunities in Brain-Computer Interfaces (BCI) and Neuroprostheses (NP) are being exploited, including current and potential future applications of NP within an eclectic approach to intervention in neurorehabilitation. Improvements in the effectiveness of contemporary neurorehabilitation emphasize the need for a shift from a specific approach to intervention to an eclectic approach to intervention. The novel strategies of BCI and NP application in an eclectic approach to intervention may be regarded as leading the way in clinical practice development. There is a limited amount of evidence both in the areas of theoretical principles and clinical applications, but it seems the application of various rehabilitation methods and techniques may effectively support the outcomes of the BCI’s and NP’s use.

Chapter 7: Chances for and Limitations of Brain-Computer Interface use in Elderly People

In this chapter, Mikołajewska et al. investigate the available opportunities and limitations in usage of Assistive Technology (AT) devices for elderly people, including medical, technical, psychological, societal, ethical, and legal issues. Recent demographic prognoses show tendencies toward significant increase in number of elderly people, especially in developed countries. This makes geriatric therapy, rehabilitation, and care difficult, especially with maintaining the highest quality of life and independence in activities of daily living as long as possible. Lack of specialized personnel and financial shortages may cause increased application of Assistive Technology (AT) and associated control devices. The most advanced current devices for diagnosis, communication, and control purposes are perceived Brain-Computer Interfaces (BCIs). BCIs are regarded as novel solutions offering another breakthrough in everyday life, care, therapy, and rehabilitation in patients with severe sensory and neuropsychological deficits. However, particular issues in the area of BCIs use in elderly people should be emphasized, including influence of neurodegenerative disorders accompanied with secondary changes resulting from other medical problems (e.g. heart diseases, hypertension, diabetes mellitus, and osteoporosis), co-occurrence of various drug therapies, etc.

Section 2: Neuroprosthetics for BCI and Other Applications

Chapter 8: Review of Applications for Wireless Brain-Computer Interface Systems

In this chapter, Soogil Woo et al. review the research trends for wireless Brain-Computer Interface (BCI) systems, as well as their current and anticipated applications. Wireless BCI systems have clear advantages, when compared to wired BCI systems, in that they have simpler shapes and can be convenient and portable devices. Recent wireless BCI applications attempt to help people live more conveniently in many areas of life: medical engineering, rehabilitation, and everyday life.
Chapter 9: Lower-Limb Neuroprostheses – Restoring Walking after Spinal Cord Injury

In this chapter, Alam and He discuss available therapies for the rehabilitation of Spinal Cord Injury (SCI) paraplegics and some new potential interventions that still require clinical tests. They also propose brain-machine-spinal cord interface as a future neuroprosthesis following motor complete SCI. Regaining lower-limb functionality such as walking is one of the highest priorities among all the disabilities of paraplegics following SCI. Though the ultimate recovery would be repairing or regenerating new axons across the spinal lesion (potentially by stem cells or other transplants and neurotropic factors), challenges to achieve this as well as recent technological advancements demand the development of new neuroprosthetic devices to restore such motor functions following the injuries.

Chapter 10: Brain-Computer Interfaces for Assessment and Communication in Disorders of Consciousness

In this chapter, Guger et al. discuss current methods and problems associated with Disorders Of Consciousness (DOC) and highlight the possible solutions to the same. Many patients with DOC are misdiagnosed for a variety of reasons. These patients typically cannot communicate. Because such patients are not provided with the needed tools, one of their basic human needs remains unsatisfied, leaving them truly locked in their bodies. This chapter first reviews current methods and problems of diagnoses and assistive technology for communication, supporting the view that advances in both respects are needed for patients with DOC. The authors also discuss possible solutions to these problems and introduce emerging developments based on EEG (Electroencephalography), fMRI (Functional Magnetic Resonance Imaging), and fNIRS (Functional Near-Infrared Spectroscopy) that have been validated with patients and healthy volunteers.

Chapter 11: Assistive Technology for Cognition – An Updated Review

In this chapter, Best, O’Neill, and Gillespie review the use of assistive technology in health and social care for people with cognitive impairment. This review updates their previous reviews on this topic and reflects on how their conceptualization of Assistive Technology for Cognition (ATC) in terms of function (reminding, alerting, micro prompting, distracting, storing, displaying, navigating, and biofeedback), as opposed to the type of technology (mobile phone, desktop computer, etc.), and fits with recent developments in this field. The authors highlight the growing number of context-aware prompting devices and the move to train people with cognitive impairment to use everyday technology such as mobile phones. They also make a distinction between ATC, which augments or supplants cognitive functions, and outline avenues for future research.
Chapter 12: Brain-Computer Interfaces for Control of Upper Extremity Neuroprostheses in Individuals with High Spinal Cord Injury

In this chapter, Rupp, Rohm and Schneiders provide an overview of the current state of the art of Brain-Computer Interface (BCI) controlled upper-extremity neuroprostheses and describe the challenges and promises for the future. For individuals with tetraplegia, restoring limited or missing grasping function is the highest priority. In patients with high Spinal Cord Injury (SCI) and a lack of surgical options, restricted upper extremity function can be improved with the use of neuroprostheses based on Functional Electrical Stimulation (FES). Grasp neuroprostheses with different degrees of complexity and invasiveness exist, although few models are available for routine clinical application. Hybrid systems combining FES with orthoses hold promise for restoring completely lost upper extremity function. Novel user interfaces integrating biosignals from several sources are needed to make full use of the many degrees of freedom of hybrid neuroprostheses. Motor Imagery (MI)-based BCIs are an emerging technology that may serve as a valuable adjunct to traditional control interfaces.

Chapter 13: Practical Artifact Removal Brain-Computer Interface System – Application to Neuroprosthetics

In this chapter, Wei-Yen Hsu presents a practical artifact removal Brain-Computer Interface (BCI) system for single-trial Electroencephalogram (EEG) data. Initially, Independent Component Analysis (ICA) combined with the use of a correlation coefficient is used to remove the EOG artifacts automatically, which can further improve classification accuracy. The features are then extracted from wavelet transform data by means of the proposed modified fractal dimension. Finally, Support Vector Machine (SVM) is used for the classification. When compared with the results obtained without using the EOG signal elimination, the proposed BCI system achieves promising results that will be effectively applied in neuroprosthetics applications.

Ganesh R. Naik
University of Technology Sydney (UTS), Australia

Yina Guo
Taiyuan University of Science and Technology, China