# Chapter 19
# Functional Electrical Stimulation Based on Interference-Driven PWM Signals for Neuro-Rehabilitation

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## ABSTRACT

*Disorders of the nervous system can cause paraplegia, which prevents human mobility and decreases quality of life. A major therapeutic goal is to recover motor and sensory function in individuals who have sensory or motor impairments, due to an accident or illness, and to provide support for the performance of daily life activities. For this purpose, the authors developed a multi-functional system based on interference-driven electrical stimulation that can promote the recovery of sensory-motor functions. The interference-driven electrical stimulation method was developed using a mixed stimulation signal with a carrier wave at a frequency that has been shown to stimulate human muscle. The parameters of electrical stimulation were optimized using a grasp/open hand task and a flexion/extension foot task based on the brain activity following electrical stimulation. This chapter reports the experimental results of the effects of electrical stimulation on motor function and brain activity in partially paralyzed stroke patients during the three phases of stroke symptoms.*

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## INTRODUCTION

A novel approach to stroke rehabilitation therapy has come from robotics technology. This approach can also be used to assist handicapped individuals, such as amputees and those with muscular disabilities or nerve diseases. The embodiment concept provided a hint as to how to integrate natural behavior and intelligence towards the useful and robust performance of cyber robotics systems. This paper reports one of the robotics approaches, a mutually adaptable prosthetic system that can recognize human intentions and includes an acceptable multi-functional mechanism of the human brain. This type of robotics technology is referred to as brain-machine interface (BMI) technology and is a promising technology for the rehabilitation of patients with serious paralytic impairments. There are two types of BMI, input and output BMI. Output BMI refers to forward man-machine interface systems that use a human's intentions to control the motion of an external robotic device using brain activity measurements obtained using methods such as electroencephalography (EEG), functional magnetic resonance imaging (f-MRI) or electrocorticograms (ECoGs). In contrast, input BMI, which is a feedback system that provides input to the brain by interacting with a robot, has been found to exhibit significant potential for neuro-rehabilitation. Many challenging studies investigating the therapeutic potential of BMI have been undertaken through collaborations between research teams from medical institutes and engineering departments. Much of this research has been designed based on event-related desynchronization (ERD) and synchronization (ERS) using specific stimulation produced by robotic devices (including electrical stimulation) according to the human intentional motion or brain activity. This is because we expect the brain naturally functions to adapt to create the preferable event.

However, ERD and ERS require feedback systems consisting of a sensing device, a robotic device, and a controller with decoding software that can predict human intension from measured brain activity. The sensing device is typically quite large, is subject to artifacts, and requires significant computational powers. Furthermore, the robotic device must exhibit real-time control of responses, a requirement that greatly complicates these systems and significantly increases costs. In addition, the experimental setup of this type of system requires a significant amount of time and work from medical doctors, physical therapists and engineers.

In this paper, we propose a feed-forward integrated system of input BMI based on functional electrical stimulation. The major advantage of this feed-forward integrated system is that it can be used by a medical doctor or physical therapist without the need of additional equipment. Before performing experiments, we determined the landscape of muscular responses and brain activity in response to various parameters of electrical stimulation. Electrical stimulation using the appropriate parameters can facilitate brain adaptations, and adaptable electrical stimulation can provide guidance for neural prosthesis to identify alternative pathways through which to control paralyzed muscles and to achieve sustainable effects of recovery. Our results shed light on the utility of electrical stimulation during the three phases of stroke symptoms: the acute phase, the convalescence phase, and the chronic phase.

## BMI RESEARCH OVERVIEW

A BMI is an example of a man-machine interface that provides a direct connection between brain activity and external devices. BMI has been studied as a potential therapeutic approach for limb paralysis of the sensory motor system, and many research institutes and universities are investigating its utility for lower leg rehabilitation. Signal detection methods are classified as either invasive or non-invasive depending upon the procedures employed. Invasive methods typically use multi-

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