Chapter 4
Harnessing Brainwaves:
Advancing EEG-Based Interfaces for Next-Generation Healthcare

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ABSTRACT

Electroencephalography (EEG)-based Brain-Computer Interface (BCI) technology has appeared as a promising path for healthcare, contributing to novel solutions for detecting, treating, and dealing with neurological conditions. By capturing and construing the electrical activities of brain signals, EEG-based BCIs empower direct brain communication with external devices, circumventing traditional neural conduits. This chapter delves into the progress of EEG-based BCI devices, emphasizing their implication in healthcare, the technical challenges tangled, and their potential to transform patient care. The key objective is to deliver a detailed exploration of the development procedure of EEG-based BCI devices, emphasizing their applications in healthcare. The chapter includes the principles of EEG signal acquisition, the design and engineering of BCI systems, the employment of machine learning algorithms for signal decoding, and the clinical validation required for medical use. Moreover, it will discuss the prospective effect of these devices on healthcare and future research directions.

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1. INTRODUCTION

The human brain produces electrical signals which replicate a broad range of cognitive and motor activities. Electroencephalography (EEG) is a non-invasive process of recording electrical signals and it has been extensively used in clinical situations to identify and monitor neurological situations such as sleep disorders, epilepsy, and brain injuries to name only a few (Wolpaw et al., 2000; Blankertz et al., 2004). With BCI technology, EEG has extended new implications as a tool for rendering brain activity into actionable instructions to control external devices (Millan et al., 2004; Pfurtscheller et al., 2000). The importance of EEG-based BCIs in healthcare is in their capability to reinstate lost functions, improve cognitive abilities, and offer new forms of communication for people with severe infirmities. To exemplify, people with Amyotrophic Lateral Sclerosis (ALS) or locked-in syndrome can practice EEG-based BCIs to converse by picking letters or words deploying their brain activity (Blankertz et al., 2004). Likewise, these devices have been engaged in neuro-rehabilitation, permitting patients to recover motor regulators after a stroke by training neural paths through BCI-driven trainings (Pfurtscheller et al., 2000; Birbaumer et al., 2006).

1.1. Categories of BCI Systems

1.1.1 Invasive / Non-Invasive BCI System

In invasive type BCI system, microelectrodes are embedded inside the skull of the subject (e.g. Electrocorticography (ECoG)). On the contrary, the non-invasive BCI devices require observing electrical brain action by retaining the electrodes on the scalp (e.g. Electroencephalography (EEG)).

1.1.2 Synchronous / Asynchronous BCI System

The BCI system of synchronous type is cue-based, referring to the user yields particular mental states by undertaking certain mental tasks in a prescheduled period with a system-initiated control. The asynchronous type BCI system is not cue-based, rather the user has freedom to initiate any specific mental task that is deliberated as control signal. Therefore, the control is initiated by the user instead of the system.