Chapter 15
Non-Manual Control Devices:
Direct Brain-Computer Interaction

Reinhold Scherer
University of Washington, USA & Graz University of Technology, Austria & Judendorf-Strassengel Clinic, Austria

Rajesh P. N. Rao
University of Washington, USA

ABSTRACT

Brain-computer interface (BCI) technology augments the human capability to interact with the environment by directly linking the brain to artificial devices. The first generation of BCIs provided simple 1D control in order to select targets on a screen or trigger pre-defined motion sequences of paralyzed limbs by means of functional electrical stimulation. BCIs today can provide users on-demand access to assistive robotic devices, Virtual Reality environments, and standard software applications such as Internet browsers. Here, we introduce readers to BCIs and review basic principles and methodologies underlying their operation. We illustrate the capabilities and limitations of modern BCI systems by discussing two practical examples: BCI-based control of a humanoid robot for physical manipulation and transport of objects in an indoor environment, and BCI-based interaction with the popular global navigation program Google Earth.

INTRODUCTION

Communicating and interacting with the environment are fundamental human capabilities. However, damage to the central nervous system due to neuromuscular disease, stroke, or traumatic brain injury can result in loss of these motor capabilities to varying degrees. In a majority of cases, individuals have largely unaltered cognitive functions, but are left with physical impairment and disability ranging from paralysis of specific parts of the body to being completely "locked-in." Exemplars of this situation include individuals suffering from degenerative neurological diseases such as amyotrophic lateral sclerosis (ALS), individuals with spinal cord injury, or survivors of a stroke.

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To manage activities of their daily lives, these individuals usually have to rely on the assistance of others. In some cases, individuals may even be unable to use conventional interfaces such as a keyboard or a computer mouse. Depending on the remaining motor function, some alternative communication aids are available, such as systems that track eye-gaze in order to select options on a computer screen, or switches that can be activated by respiration (e.g., by sucking on a straw) to give “yes” or “no” answers.

Brain-Computer Interface (BCI) technologies provide a novel way for humans to interact with machines. BCIs are not dependent on actual movements; instead, BCIs process the user’s intent directly and translate the corresponding brain activity into control commands for devices (Wolpaw, 2002; Dornhege, 2007). The information transfer rate (ITR) of BCIs is low compared to muscle operated devices, usually less than 30 bit min^{-1}. Disabled and able-bodied individuals, however, have learned to successfully operate BCI-based devices to compose messages on a computer (Birbaumer, 1999; Neuper, 2003; Scherer, 2004; Piccione, 2006; Sellers, 2006; Williamson, 2009), browse the internet (Bensch, 2007), control robotic assistive devices (Millán, 2004, Bell, 2008, Galán, 2008) and, to some extent, also restore lost motor function (e.g., by controlling a neuroprosthesis, Pfurtscheller, 2003; Müller-Putz, 2005a). Some of these achievements were not reached in isolated laboratory environments, but in patient homes or clinical settings. These promising first results show that the technology has evolved to a state where it may be ready to be tested and evaluated in real world environments.

The goal of this chapter is to introduce readers to the field of BCIs and to review basic principles and currently used methodologies. Practical examples are provided in order to illustrate the usage, the performance, and also the limitations of modern BCI systems. Due to the limited space available, we are unable to provide extensive details and have had to omit some important alternative approaches and associated references. The chapter emphasizes those approaches which have been extensively evaluated by our group and demonstrated to be useful in practical applications. We also discuss new trends and ideas, in order to stimulate further research in this compelling new area.

BACKGROUND

Figure 1 illustrates the basic steps involved in direct brain-computer interaction. To establish closed-loop interaction, the user’s brain activity has to be first monitored and digitized (signal acquisition). Second, signal processing methods are applied to extract features of interest from the acquired signal and classification (or regression) methods are used to translate them into control commands for a device (pattern recognition and machine learning). The user perceives the initiated action and this sensory feedback closes the loop.

The following sections briefly review available recording technologies, brain signals used for operating BCIs, and commonly used pattern recognition and machine learning methods.

Signal Acquisition

Three different types of brain signals have been used in BCI research. First, electrical signals reflecting neuronal activity in the brain can be recorded in one of three ways: (i) electrodes placed on the scalp (electroencephalogram, EEG) (Birbaumer, 1999; Millán, 2003; Pineda, 2003; Pfurtscheller, 2006; Vaughan, 2006; Blankertz, 2006), (ii) electrodes placed on the surface of the cortex without penetrating the cortex (electrocorticogram, ECoG) (Miller; 2007, Schalk, 2008; Scherer, 2009), or (iii) electrodes placed within the cortex (intracortical single unit or multiunit recordings) (Maynard, 1997; Hochberg, 2006). Second, rather than measuring electrical activity, one can use magnetoencephalography (MEG) to