ELECTROPHYSIOLOGICALLY INTERACTIVE HUMAN-COMPUTER INTERFACES

Adrijan Božinovski
University American College
Skopje, Macedonia

Liljana Božinovska
South Carolina State University
Orangeburg, SC, USA

Stanko Tonković
University of Zagreb
Zagreb, Croatia

ABSTRACT

This work addresses the status of systems that implement electrophysiological interaction between a human and machines. Special attention is given to robot control using electrophysiological signals from a human head. The work includes practical realization of controlling robots using such signals.

I. INTRODUCTION

Any object, product, system, or service that will be used by humans has the potential for usability problems and should be subject to some form of usability engineering [12]. Cell phones, consumer electronics, and web interfaces are all examples of wide use of design for interactive use [19]. Human-computer interaction (HCI) is just one focus of usability engineering research. Human computer interaction offers wide variety of interaction modes, including multimedia modes, between humans and computers.

Several generations of human-computer interaction have been noticed. Starting with the batch interface and punched cards (IBM 1130), an important step was the interactive terminal and command line (e.g. PDP 11). Almost revolutionary was the PC approach (Apple, Spectrum, Commodore, PC) when humans accepted personal computers and their ports like parallel, serial, etc. The next step was the full-screen graphical user interface and a screen pointing device ("mouse"). Windows-oriented operating systems (Macintosh) expanded the usability range to users like musicians and many others. Elements like buttons and drop-down menus have become standard in human-computer interaction. Today, sound cards and cameras are standard devices with laptops and cell phones.

Feedback from the user and *user modelling* has become an important issue. Various methods have been implemented to acquire feedback from the users – interviews, questionnaires, and data analysis were implemented, generating models of the user. Having models of their users, companies like Amazon offer books and other things according to user preferences.

Various aspects of usability have been studied, including emotional aspects of the user, such as positive emotions and frustrating interfaces as well. Anthropomorphic agents, virtual pets, and other software emotion-related tools were used to improve the human-computer interaction [16].

That is the stage where we are now in human-computer interaction. There is always the question what is the next stage. Among many possibilities, we foresee interfaces based on electrophysiologically interactive human-computer interfaces (EHCI). Those types of devices will be the focus of this work.

II. ELECTROPHYSIOLOGICAL HUMAN-COMPUTER INTERACTION (EHCI)

There are studies of the potential for electrophysiological human computer interfaces [1]. Several scenarios could be observed.

A. Monitoring-Oriented Scenarios

Monitoring-oriented scenarios are used in applications for gathering user data from which they can deduce the medical or emotional status. For example, good indicators of arousal are the heart rate and skin conductance. They might be integral data sources for emotional-state related EHCIs.

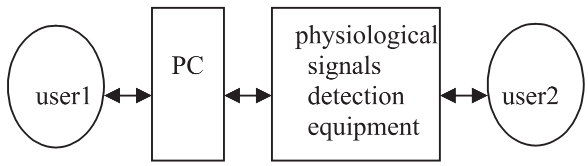

Figure 1: A monitoring EHCI

Also, physiological states such as stress, high anxiety, absorption, fatigue, and inattention can be potentially dangerous for an operator, so an EHCI monitoring state of a locomotive driver would be a valuable toward safety improvement, for example.

B. Control-Oriented Scenarios

Monitoring EHCIs are usually open-loop, whereas control systems are usually closed-loop. Detecting physiological changes and relaying them back to the subject audibly or visually in real time (biofeedback) is another important application of an EHCI.

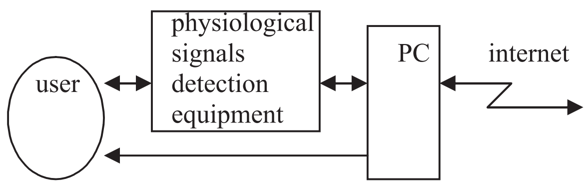

Figure 2: Closed-loop EHCI

Interfaces to existing biofeedback applications range from interactive 2D graphical tasks (in which muscle signals are amplified and transformed into control tasks such as lifting a virtual dumbbell), to real-world physical tasks including radio-controlled devices.

Today, EEG feedback and neurofeedback is used for the treatment of psychophysiological disorders such as attention deficit/hyperactivity disorder, post-traumatic stress disorder, addictions, anxiety and depression. Surface-mounted electrodes detect EEG and present it to the subject as abstract images in real time. Using this data in reward/response based control tasks generates increased or reduced activity in different aspects of the EEG spectrum to help ameliorate these psychophysiological disorders.

C. *Hands-free Operation: Head-computer Interface*

An important part of an EHCI is the application in hands-free operations. It is a challenging application area of prosthetics for the handicapped, of the need for additional ways of control when the hands are busy, and for controlling devices simply using mind.

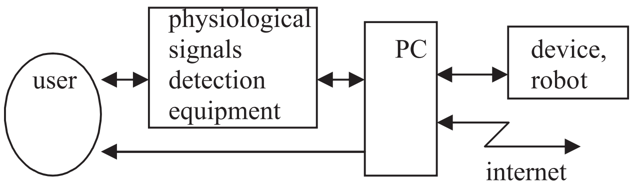

Figure 3: Hands-free control EHCI

An important part of hands-free control is the brain-computer interface paradigm [13]. We understand the brain-computer interface (BCI) as a system which can derive meaningful information directly from the human brain in real time and possibly use that information for control purposes.

The brain communicates with its environment usually through peripheral nerves and muscles. In a brain-computer interface paradigm, the brain uses direct bioelectric communication with the external world without its normal output through the peripheral nerves and muscles.

Let us mention some of the milestones in brain-computer interface research. EEG was first introduced by Berger [2]. The possibility of controlling devices using EEG was mentioned by Vidal [18]. Alpha rhythm was proposed to be used by Osaka [14]. The concept of mental prosthesis was introduced by Farwell and Donchin [7]. The first control of a mobile robot using EEG alpha rhythm took place in Macedonia [4]. In the 1990s [8], BCI experiences its renaissance. A cursor was moved on a computer screen using EEG [19]. The term Brain-Computer interface was introduced by Pfurtscheller et al. [15]. The importance of digital signal processing in BCI was emphasized by McFarland et al. [10]. Alpha rhythm was again used as a mind switch [5]. The concept of imaginary voluntary movement-related potentials (IVMRP) was introduced by Mason and Birch [9]. Cognitive processes based BCI were introduced starting 2000. A P300-based BCI was proposed by Donchin et al [6]. A CNV-based BCI was introduced by Božinovski [3].

There are two approaches towards BCI control. The first one is a non-invasive scalp-recording-EEG-based BCI, used with humans. Invasive methods are used on animals. Open-brain BCI with recordings directly from the animal's brain tissue was used to show the ability of a brain to control a robot arm [11].

III. Basic Compoinents of a Brain-Computer Interface

A brain-computer interface paradigm consists of a subject that generates biosignals from the brain, a computer that contains software for EEG processing, and a device that would be controlled by the EEG signals. Applications include cursor movement, wheelchair movement, spelling programs, TV on/off, etc. Since a BCI must operate *either in real-time or near-real-time,* it is important that the signal processing not introduce unacceptable time delays.

The following interrelated steps are fundamental to the design and use of a BCI: 1) The mental process of the user, which encodes commands in the EEG signal and 2) the BCI, which, by employing signal processing techniques, translates the EEG signal characteristics into commands which control a device.

One of the techniques used is the imagination of different simple hand and feet movements, which are associated with different EEG patterns. The related mental process (motor imagery) is identical to the process that results in an actual physical (muscle) movement, except that the motor activity is blocked.

The most common technique for extracting features from an EEG signal is to analyze its spectral power in different frequency bands. The frequency bands are selected in such a way so that they reflect the EEG rhythms of interest. In addition to the classical alpha rhythm, the mu rhythm and the beta rhythm have also been found useful for BCI applications. While the alpha rhythm is recorded from close to the visual cortex, the mu and beta rhythms are recorded close to the sensory-motor cortex, i.e., the area which is primarily responsible for the control of hand and foot movements.

IV. Our Research in the EHCI

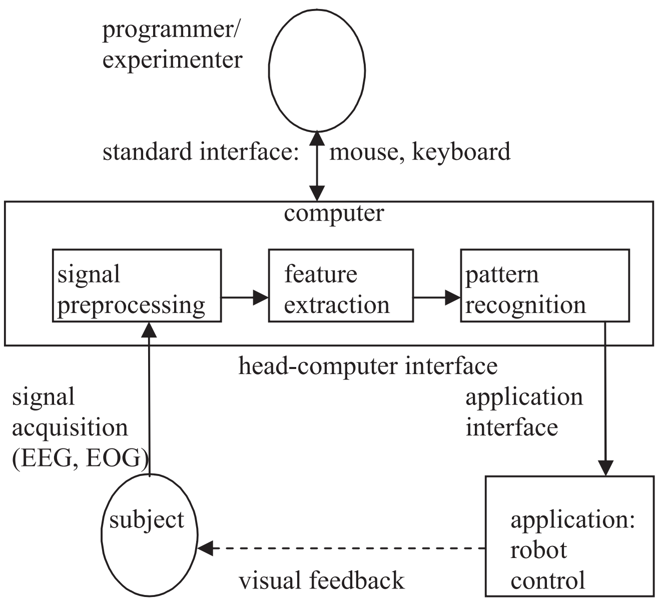

Figure 4: Head-computer EHCI

We are interested in electrophysiologicaly interactive interfaces for controlling devices (e.g. robots), using signals from a human head, such as EEG and EOG. Fig. 4 shows the experimental setup we use.

Fig. 4 shows that two subjects are used, but we should mention that in the development phase the programmer is also the subject: he/she is the programmer in program development and compile time, and the subject in program runtime.

The software we developed has screen design as shown in Fig. 5. It shows an experiment with EEG control.

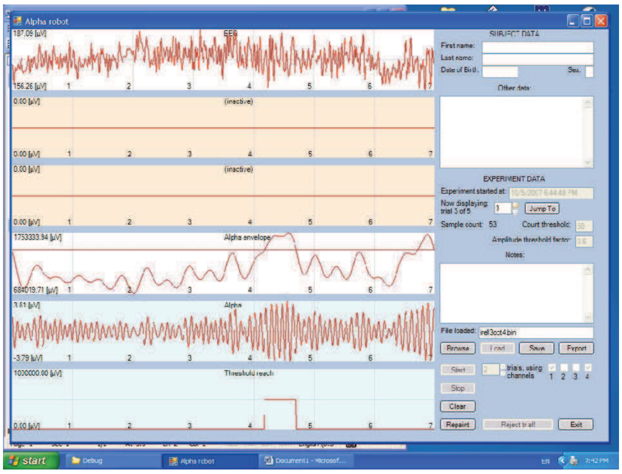

Figure 5: EEG-based EHCI

The first channel on the screen shows the acquired EEG, 7 seconds acquisition. The acquisition starts with a beep signal and ends with a beep signal. The subject is told to close his/her eyes after counting to 3, about at the middle of the recorded segment. A digital filter extracts the alpha rhythm on channel 5. Another digital filter computes the envelope of the alpha rhythm and shows it on channel 4. The envelope amplitude is compared against a threshold in the interval between the 1st and 6th second. As long as the alpha rhythm amplitude is greater that the threshold, a signal is sent to a robot motor and robot moves.

The software we developed for EOG device control has a screen design as shown in Fig. 6. It shows an experiment with EOG control.

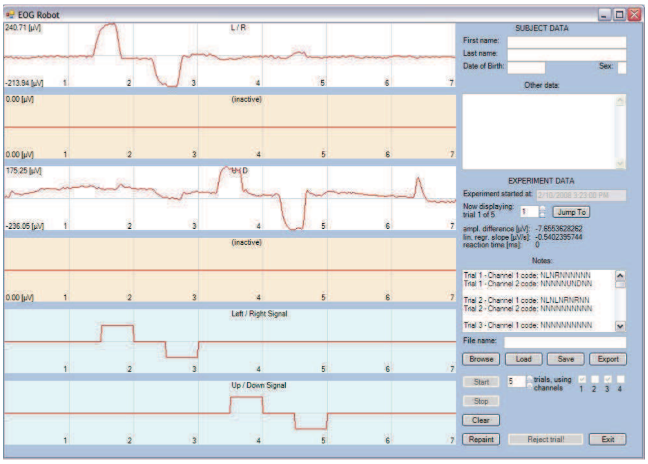

Figure 6: EOG-based EHCI

The first channel records horizontal movement of the eyes, while the third one records the vertical movement of the eyes. The software compares the amplitudes with a threshold value and sends signals to motors, as shown in channels 5 and 6 respectively. At this stage of software development we control one robot arm motor with horizontal and one with vertical eye movement.

V. CONCLUSION

The development of electrophysiologically interactive computer interfaces will enable the creation of truly personal computers: systems that read and understand their users' signatory physiology. This will improve our interaction with machines as well as help us learn more about our psychophysiological selves. Combining computing with physiological sensing technologies will transform human-machine interaction and usher in a wide range of new applications.

In our research we are just a part of that effort with our effort in controlling machines using signals from human head.

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