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Human-Computer Interfaces and Anticipatory Brain Potentials

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ABSTRACT: This work gives an overview of the status in the area of human-computer interface and our work in that area. We are especially interested in the brain-computer interface, where we explore the paradigms with anticipatory brain potentials. A research system was developed and experiments were carried out in the area of expectancy potentials, particularly the CNV potential, using the brain-computer interface framework. In particular, this work reports on obtaining the CNV potential without motor action after some training.

KEYWORDS: human-computer interface, biosignal processing algorithms, anticipatory brain potentials, C# programming

I. INTRODUCTION

Any object, product, system, or service that will be used by humans has the potential for usability problems and should be subjected to some form of usability engineering [12], [17]. Human-computer interface (HCI) is just one focus of usability engineering research. Human-computer interaction offers a wide variety of interaction modes between humans and computers

Several generations of human-computer interaction have been noticed. Starting with batch interfaces 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, along with their ports (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 became standard in human-computer interaction. The World Wide Web expanded the use of computers in everyday life. Today, sound cards and cameras are standard devices for laptops and cell phones.

Feedback from the user and user modelling become important issues. Various methods have been implemented to acquire feedback from the users, including interviews, questionnaires, and data analysis, which are implemented to generate models of the users. Having models of their users, companies like Amazon offer books and other things according to user preferences, for example.Various aspects of usability have been studied, including emotional aspects of the users, 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 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 potentials of the electrophysiological human-computer interfaces [1]. Several scenarios could be observed.

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A. Monitoring-Oriented Scenarios

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

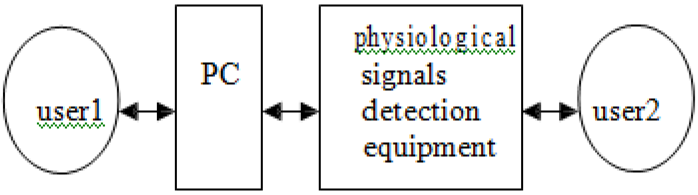

Figure 1. Monitoring-oriented EHCI

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

B. Control-Oriented Scenarios

Monitoring-oriented EHCIs are usually open-loop. Control systems are usually closed-loop: physiological changes are detected and relayed back to the subject audibly or visually in real time. This is called biofeedback and is another important application of an EHCI (Figure 2).

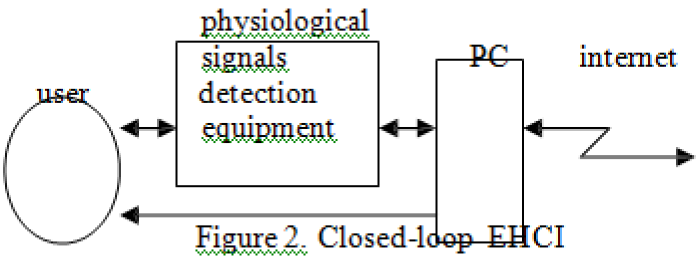

Figure 2. Closed-loop EHCI

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 treating psychophysiological disorders such as attention deficit, hyperactivity disorder, post-traumatic stress disorder, addictions, anxiety, and depression. Surface-mounted electrodes detect EEG and present it back to the subject ain the form of 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 its application in hands-free operations (Figure 3).

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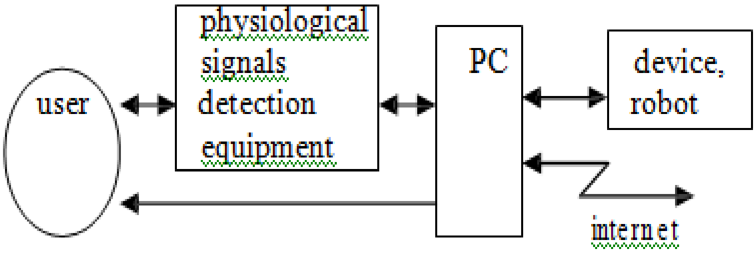

Figure 3.Hands-free-controlled EHCI

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 the mind.

III. THE BRAIN-COMPUTER INTERFACE (BCI) PARADIGM

An important part of hands-free control is the brain-computer interface paradigm [13]. We understand the brain-computer interface (BCI) is a system which can derive meaningful information directly from the human brain in real time or near-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 peripheral nerves and muscles.

Following are 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 [3]. In the 1990s [8], BCI experiences its renaissance. A cursor was moved on a computer screen using EEG [20]. 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 [9]. Cognitive-processes-based BCIs were introduced starting 2000. A P300-based BCI was proposed by Donchin et al [6]. A CNV-based BCI was introduced by Božinovski [4].

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

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 program, 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 features into commands, which control a device.

One of the techniques used is the imagining 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 muscle movement, except that the motor activity is blocked.

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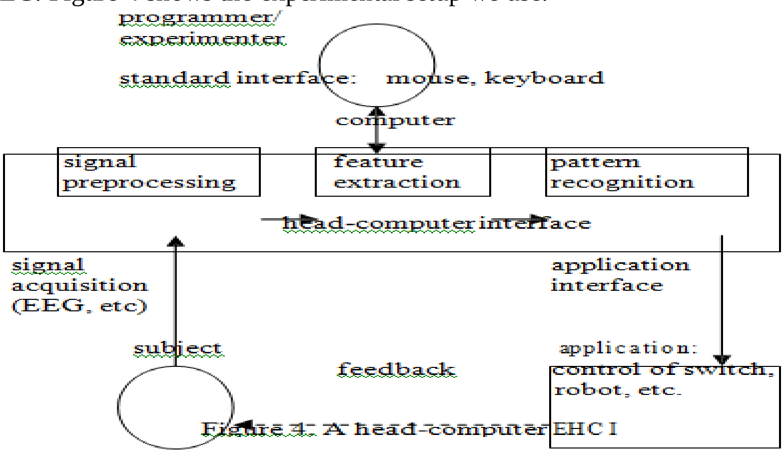
The most common technique for extracting features from an EEG signal is to analyze its spectral power in different frequency bands. The frequency bands are selected so that they reflect the EEG rhythms of interest. In addition to the classical alpha rhythm, the mu rhythm and the beta rhythm have been found useful for BCI. 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 movement.

IV. OUR RESEARCH IN THE BCI

We are interested in electrophysiologically interactive interfaces for controlling devices using signals from the human head, such as EEG. Figure 4 shows the experimental setup we use.



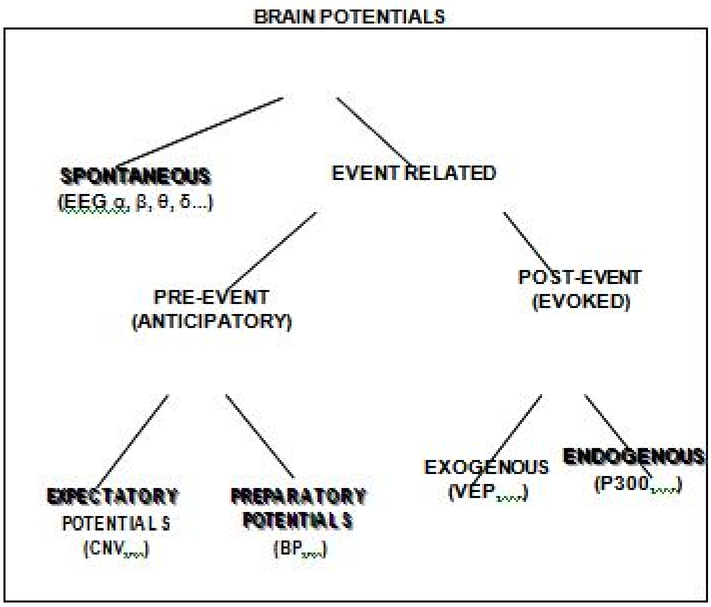


Figure 5.A taxonomy of the brain potentials

The anticipatory brain potentials are divided into expectatory and preparatory. The preparatory potentials are a preparation for action, for example preparation for pressing a piano key; the most well-known example is the

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Beretschaftspotential. The expectatory potentials appear as expectation for some event. The most well-known is the Contingent Negative Variation (CNV) potential [19], on which this paper focuses.

The CNV potential appears in a CNV experimental paradigm (Figure 6).

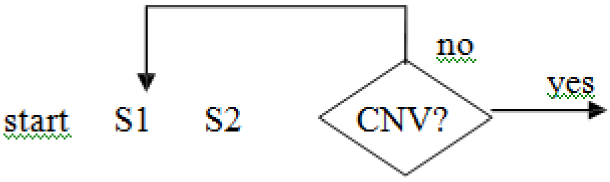

Figure 6. The classical CNV paradigm

Figure 4 shows that two subjects are used, but we should mention that in the development phase the programmer and yesthe subject are the same person, being the programmer in program development and compile time, and the subject in program runtime.

A. Anticipatory Brain Potentials

The electrical activity of the brain (EEG) is the most frequently used source of signals in a head-computer interface. EEG is a recording of electrical signals from the brain under various conditions. Various electrical potentials were revealed so far and a possible taxonomy of those potentials is shown on Figure 5.

As Figure 5 shows, the brain potentials are divided into spontaneous and event related. Event related potentials (ERPs) are divided into evoked and anticipatory. Evoked potentials appear after an event, for example after a sound signal. Evoked potentials are divided into exogenous and endogenous. Exogenous evoked potentials appear as a reflex response to an event. They possibly represent the sensory reaction to the event. Examples are the visual evoked potentials (VEP), auditory evoked potentials (AEP), and so on. Endogenous evoked potentials appear after the exogenous. They are cognitive reactions to the event, and possibly represent a pattern recognition effort of the brain, related to the event. An example is the P300 potential, which appears about 300ms after the event.Figure 6. The classical CNV paradigm

It is actually a standard reaction-time measurement paradigm, in which EEG is measured. The subject is presented with two stimuli: a warning one (S1) and an imperative one (S2). The first one is short, while the second one lasts until the subject stops it by pressing a button. Reaction time (RT) is measured between S2 and pressing the button. If EEG is recorded during this reaction time paradigm, and if in the process an ERP is extracted from the EEG, a special ERP shape is usually obtained, which is named CNV.

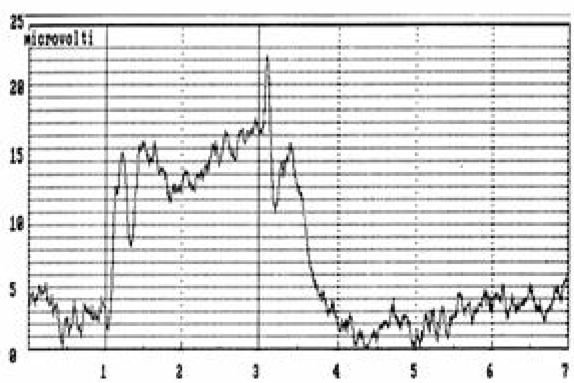

Figure 7. The morphology of a CNV potential

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Figure 7 shows the morphology of a CNV potential. As we can see from Figure 7, the CNV feature is a ramp-like shape between S1 and S2, ceasing after S2. It is a rather complex potential, containing both exogenous and endogenous components to both S1 and S2.

B. The CNV Flip-flop Paradigm

In our research we introduced a feedback loop on the CNV paradigm. The paradigm is computer-controlled and Figure 8 shows the modified CNV paradigm we use in this research.

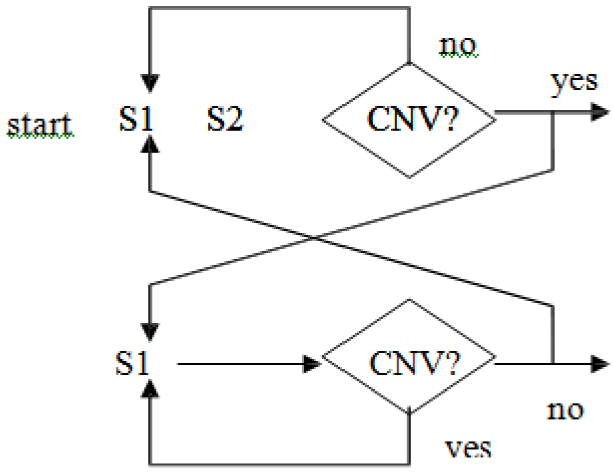

Figure 8. The CNV flip-flop paradigm

The system records from 4 channels. The first channel is the EEG channel, the second channel is the EMG channel, the third channel is the EOG channel, and the fourth channel is the press-button sensor channel. Channel 5 computes and shows the S1-S2-RT relation, and Channel 6 shows the ERP extracted from the EEG. Channel 6 also mirrors the S1-S2-RT relation, using vertical marks. The screen also contains information about the subject, as well as information and control of the experiment.

The experiments were carried out in the Laboratory of Neurophysiology, Institute of Physiology, Medical Faculty in Skopje, Macedonia. Students were used as subjects. An experiment usually lasts more than 30 trials. Figure 7 inAs Figure 8 shows, after the classical part of the CNV paradigm, in which the S1-S2 pair of stimuli is administered and the CNV appears, the computer turns off the S2 stimulus. Since S2 is not present anymore, there is no expectancy on S2 and the CNV shape degrades into some other ERP shape. The computer recognizes the CNV is not present, and turns on the signal S2 again. In such a way, we obtain a paradigm in which the CNV appears (flips) and disappears (flops). This is called the CNV flip-flop paradigm [4], after a basic memory device known in digital circuits.

C. Materials and Methods

The basis of our methodology is a software tool that acts as a BCI in our research. Figure 9 shows the user interface part of the system. The software was developed using the C# programming language.

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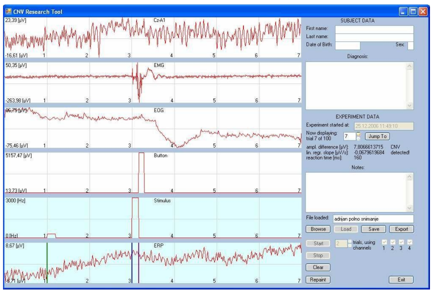

Figure 9. The user interface screen of our research system

the CNV can be obtained with no press button movement. Figure 10 shows such a case.The system records from 4 channels. The first channel is the EEG channel, the second channel is the EMG channel, the third channel is the EOG channel, and the fourth channel is the press-button sensor channel. Channel 5 computes and shows the S1-S2-RT relation, and Channel 6 shows the ERP extracted from the EEG. Channel 6 also mirrors the S1-S2-RT relation, using vertical marks. The screen also contains information about the subject, as well as information and control of the experiment

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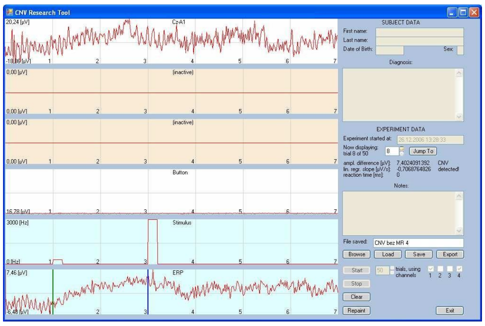

Figure 10. Obtaining CNV with no motor action

In this modified paradigm, both S1 and S2 are administered with fixed length. No press button is included in the paradigm and consequently no reaction time is measured. As Figure 10 shows, we did not record from EMG, EOG, and press button channels. It also shows that after 8 trials we were able to obtain the CNV signal. We should note however, that this recording is obtained from a subject already experienced with the CNV paradigm. So we would say that, in a no-press- button CNV paradigm with an experienced subject, the CNV is generated as quickly as in a classical CNV paradigm.
physiological sensing technologies will transform human- machine interaction and usher in a wide range of new applications. interface paradigm. We developed a software research tool for this paradigm. Using that software tool we were able to show how a CNV can be obtained with no press-button component in the CNV paradigm. With this work we contributed to the area of research related to the electrophysiological phenomena contingent to expectancy and learning.

Our further work is planned to be towards the observation of the dynamics of the CNV wave in a CNV flip-flop paradigm. We also plan to link the CNV flip-flop paradigm with robot control.

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In our research we are just a part of that effort with our effort, This work is a continuation of a closed-loop CNV paradigm.
It introduced the concept of a flop-flop paradigm and
particular shows trial 7 of a total of 100 trials in this experiment. The ERP amplitude difference is sufficiently high, so that the computer recognizes it as a CNV, and writes that on the experimental data part of the screen.

It is an open question whether the CNV can be achieved by imagining the motor movement. We did not do so in our case. That's why we believe that CNV is a truly expectatory signal.

V. CONCLUSION AND FURTHER WORK

The development of electrophysiologically interactive computer interfaces will enable the creation of truly personal computers, i.e. systems that read and understand their users' signatory physiology. This will improve human interaction with computers, as well as help us learn more about our psychophysiological selves. Combining computing with

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