 DOI:10.3217/978-3-85125-378-8-78

Augmenting communication, emotion expression and interaction capabilities of individuals with cerebral palsy

Reinhold Scherer[1], Johanna Wagner[1], Martin Billinger[1], Gernot Müller-Putz[1], Rafael Raya[2], Eduardo Rocon de Lima[2], Yehva Mohamad[3], Dirk Tassilo Hettich[4], Elaina Bolinger[4], Marco Iosa[5], Febo Cincotti[5], Ana Rita Londral[6], Joana Mesquita[6], Mariano Lloria Garcia[7] and Juanma Belda[8]

[1] Institute for Knowledge Discovery, Graz University of Technology, Graz, Austria
{reinhold.scherer, johanna.wagner, martin.billinger, gernot.mueller}@tugraz.at
[2] Bioengineering Group, Spanish National Council for Science Research (CSIC), Madrid Spain
{rafael.raya, e.rocon}@csic.es
[3] Fraunhofer FIT, Sankt Augustin, Germany
yehya.mohamad@fit.fraunhofer.de
[4] Erberhard-Karls-University of Tübingen, Tübingen, Germany
dirk-tassilo.hettich@uni-tuebingen.de, elaina.bolinger@med.uni-tuebingen.de
[5] Neuroelectrical Imaging and BCI Lab, IRCCS Fondazione Santa Lucia, Rome, Italy
{m.iosa, f.cincotti}@hsantalucia.it
[6] PLUX Wireless Biosignals, Lisbon, Portugal
{alondral, jmesquita}@plux.info
[7] Avapace, Asociacion Valenciana de ayuda a la paralisis cerebral, Valencia, Spain
coordinacion@avapace.org
[8] Insituto de Biomecanica de Valencia, Universitat Politecnia de Valencia, Valencia, Spain
juanma.belda@ibv.upv.es

Abstract

Providing individuals with cerebral palsy (CP) tools to communicate and interact with the environment independently and reliably since childhood would allow for a more active participation in education and social life. We outline first steps towards the development of such a hybrid brain-computer interface-based (BCI) communication tool.

1 Introduction

Cerebral palsy (CP) is a non-progressive condition caused by damage to the brain during early developmental stages (annual incidence of 2 per 1000 live births in Europe). Individuals with CP may have a range of problems related to motor control, speech, comprehension, or mental retardation. The majority of children with CP have normal intelligence, however, due to lack of appropriate communication means they are classified as educational abnormal. Communication solutions are available; however, they strongly depend on motor activity and assistance of others.

The aim of the ABC project (`http://abc-project.eu`) is to develop an interface for individuals with CP that improves independent interaction, enhances non-verbal communication and allows expressing and managing emotions. Both motor activity and (electro)physiological signals will serve as input for the interface. In fact, one key component of the ABC system is a non-invasive electroencephalogram-based (EEG) brain-computer interface (BCI). In this paper, we outline the basic structure of the ABC system and briefly report on the functionality of individual modules, which were developed following user-centered design principles, i.e., in accordance with user needs and requirements defined in terms of usability and functionality.

DOI:10.3217/978-3-85125-378-8-78

2 Functional ABC Prototype Modules

The ABC system has three main functions: (i) Intentional communication (by use of EEG, electromyography (EMG) and inertial measurement units (IMUs)), (ii) emotion expression and management (by EEG, and electro-dermal activity (EDA) and blood volume pulse (BVP) sensors placed at the wrist), and (iii) health monitoring (by use of a sensing chest band with electrocardiogram (ECG), respiration and accelerometer sensors). The Communicator application is the graphical user interface (GUI) for accessing all features of the ABC system

2.1 Communicator

The Communicator application provides different pointing and scanning techniques (dependent on input signal) for selecting available options. Menu options (pictograms) describing the actions to be executed (e.g. access to video, music or social network) are arranged in a grid (matrix). Audio and visual feedback informs the user about selected choices and the action being performed. Changes in the affective state of the user and vital health parameters are shown in a status window. As impairments and capabilities in CP users vary considerably between individuals, the communication with the system can be tailored to the specific needs and capabilities of each individual user.

2.2 Communication

2.2.1 EEG-based interface

Developing BCIs for CP user is challenging for several reasons. Firstly, more or less frequent spasms and involuntary movements negatively impact on the EEG signal quality. Secondly, BCI paradigms have mostly been developed for able-bodied individuals. Hence, experimental paradigms need to be adapted to the end-users capabilities following user-centered design principles. Thirdly, data collection is time consuming and tedious for the user. Hence, besides the need to develop novel motivating training paradigms, machine learning methods need to be improved in a way to handle the lack of training data and infer robust models that predict the users intend from EEG signals [1, 2].

An imagery-based BCI (brain-switch) was developed to give CP users on-demand access to the Communicator by row-column scanning protocols. Spontaneous EEG oscillations were selected instead of evoked-potentials to encode messages to avoid the risk of epileptic seizures in younger CP users. Note, that the prototype will be most useful to children. To enhance robustness and reliability of mental imagery detection during early training, i.e., when activity patterns are usually not well established and correct detection may be challenging, selection redundancies were integrated. Currently user have to confirm a selection $n = 3$ out of $m = 5$ times. Test in healthy users confirm that, at the cost of an increased selection time, the developed strategy enables users to make robust selections even when binary classification performance was around 80%. Experiments in CP users are currently in progress.

One core component of the BCI system is a novel fully-automatic artifact reduction method [3]. The method, based on online Wavelet decomposition, independent component analysis and thresholding, automatically removes a number of different artifacts while preserving information that is useful for BCI. Experiments in healthy users suggest that BCI operation is still possible while users for example walk and hold objects with their hand [4].

 DOI:10.3217/978-3-85125-378-8-78

2.2.2 Head mounted interface

A head-mounted interface based on inertial technology has been developed. This interface translates head movements and posture of the user with CP into mouse pointer positions following an absolute control (based on angular orientation). The inertial interface consists of a headset with an inertial measurement unit (IMU). The IMU integrates a three-axis gyroscope, accelerometer and magnetometer. The first study was focused on characterizing the motor capabilities and abnormalities of users with CP. The task consisted in reaching targets on the screen using the head motion. We selected some outcome metrics to evaluate the performance of the users. Three healthy subjects participated as control group. 1) Throughput (TP), a metric proposed by the ISO9241 that measures the usability of the interface, 2) Frequency (f) of the head motion, aiming to identify some abnormal movements such as tremor or spasms, 3) Range of motion (ROM) of the head, aiming to identify difficulty to maintain the posture to control the interface. Results showed that there are no significant differences between users with CP and healthy control participant in the frequency domain of the head movement. However, there are significant differences for posture control between healthy users and subjects with CP. This result suggests that posture control leads to a lack of usability more than high frequency movements. The results and conclusions of this work are considered an objective description of user needs, which should be used to optimize the inertial interface. Based on these results, a new control mode based on angular velocity (relative) instead of orientation (absolute) has been implemented. Additionally, the EMG signal is being studied to generate the click in a natural way instead of dwell click that resulted complicated for users with CP.

2.3 Emotion detection and communication

Auditory affect induction paradigms based on short emotionally-laden sounds from the International Affective Digitized Sounds (2nd edition) database were developed to investigate electro-dermal activity (EDA) and EEG activity of emotional processing in individuals with CP in the absence of the ability to visually fixate on traditional emotional imagery.

An EDA-based emotion detection module was developed that discriminates between five distinct affective states: high arousal positive, low arousal positive, neutral, low arousal negative and high arousal negative. An average 5-class classification performance of 80% was computed over 12 CP users. To implement a reaction of the system to the detected emotional state e.g. play music, we have furthermore developed an emotion management system (EMS). EMS allows the caregiver of CP users to define how the system reacts to the current detected emotional state. EMS was evaluated with 15 CP users. All users appreciated the EMS and gave many suggestions for improvements, the majority of these suggestions has been implemented.

EEG-based emotion detection is work in progress. Time and frequency domain EEG features of emotion, such as the late positive potential (LPP), as well as valence-dependent inter-hemispheric alpha and event-related de/synchronization effects were analyzed. Promising preliminary LPP and inter-hemispheric alpha activity results are comparable to literature from a healthy population. Movement artifact-contaminated EEG, however, resulted in low accuracies in CP users. The custom developed artifact rejection method is currently being adapted to clean the data.

2.4 Health Monitoring

The main health-related problem of individuals with CP is dyspnea. In fact, 59% of the immediate causes of death in this population are diseases related to respiratory system; other

 DOI:10.3217/978-3-85125-378-8-78

21% are related to infections and inflammations of the lungs (pneumonia). Accordingly, a health monitoring module was integrated into the ABC prototype. Conceptually, it is divided into clinical health monitoring for severely affected people and physical activity monitoring for mildly affected ones. Movement artifacts make clinical health-state monitoring challenging. The system, however, provides helpful information on vital parameters during sleep or periods of reduced movement activity. The accelerometer embedded in the chest band provides important information on the quantity of locomotion performed by the individual during the day. This information can be therapeutically important for mildly to moderately affected individuals.

3 Conclusion and Future Work

The ABC prototype is a modular and flexible system that can be adapted according to the users need. This is especially important for CP users as impairments and capabilities vary considerably between individuals. Pilot studies with the head mounted IMU interface and emotion detection by EDA activity show that these methods can be applied reasonably well and are accepted by CP users. Besides improving robustness and performance of the developed functions, in a next step individuals modules will be tested in daily use by CP users.

Movement artifacts are one major issue for the sensor network and EEG signals are most severely affected. To ensure that correlates of cortical activity are used for BCI control, focus was put on the characterization of "clean" EEG and the development of artifact reduction and detection methods. A novel robust protocol for imagery-BCI based interaction has been tested in healthy users and is currently being evaluated in CP users. Note, results in healthy users cannot directly be transferred to real life situation in users with CP. In a next step the prototype will be updated according to the CP users comments and training paradigms will be adapted. The updated ABC prototype system will provide an excellent basis to study advantages and limitations of imagery-BCI control in CP. We expect that, the system will allow us to identify scenarios and applications where CP users truly benefit from the use of BCI technology.

Acknowledgments

This work was supported by the FP7 Framework EU Research Project ABC (No. 287774). This paper only reflects the authors views and funding agencies are not liable for any use that may be made of the information contained herein.

References

[1] I. Daly, M. Billinger, J. Laparra-Hernández, F. Aloise, M. Lloria Garcia, J. Faller, R. Scherer, and G. Müller-Putz. On the control of brain-computer interfaces by users with cerebral palsy. *Clinical Neurophysiology*, 124(9):1787–1797, 2013.

[2] I. Daly, J. Faller, R. Scherer, C.M. Sweeney-Reed, S.J. Nasuto, M. Billinger, and G.R. Müller-Putz. Exploration of the neural correlates of cerebral palsy for sensorimotor bci control. *Front Neuroeng*, 7:20, 2014.

[3] I. Daly, R. Scherer, M. Billinger, and G. Müller-Putz. Force: Fully online and automated artifact removal for brain-computer interfacing. *IEEE Trans Neural Systems Rehab Eng*, accepted.

[4] R. Scherer, J. Wagner, M. Billinger, and G. Müller-Putz. Online artifact reduction and sequential evidence accumulation enhances robustness of thought-based interaction. In *Proceedings of the 6th International BCI Conference, Sep. 16-19, 2014, Graz, Austria*, 2014.