Non-Invasive Brain Imaging Technique for Playing Chess with Brain-Computer Interface

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Abstract— **This paper introduces brain-computer interface (BCI) as the human-machine interface (HMI) that can be seen as the bridge that is building up direct one-way or two-way communication pathway between the brain and the computer or other external technical device. Brain-computer interface is based on acquisition, analysis and transformation of signals that are generated by the central nervous system (CNS) especially the brain as the manifestation of its normal function. Paper defines the BCI and introduces various areas of BCI application. The main focus of this paper is in the introduction of various techniques of brain imaging which are divided into two main groups - structural and functional brain imaging. Special attention is paid to functional brain imaging techniques and mainly to those that are non-invasive, especially multi-channel electroencephalography (EEG) that is reading electrical activity of the brain from the scalp of the subject without any invasion to the body of the subject. This technique is widely used in building of BCIs not only because of its non-invasivity, but also because of the capability of the high temporal resolution with possibility to measure electrical activity of the brain with high time resolution on the level of milliseconds. As the part of this paper we are introducing our experience with the low-cost commercially available equipment Emotiv EPOC Neuroheadset based on multi-channel electroencephalography (EEG) and we are introducing application that allows playing chess with use of the brain-computer interface built with the Emotiv EPOC Neuroheadset.**

***Keywords-** user interface; brain computer interface; BCI; human-machine interface; structural brain imaging; functional brain imaging; multi-channel electroencephalography; EEG; emotiv EPOC neuroheadset*

I. INTRODUCTION

Brain-computer interface (BCI) research, as the interdisciplinary field on the borders of biology, medicine and informatics, has attracted a lot of attention of scientific community in recent years.

Brain-computer interface is often evaluated as the potential part of the equipment able to improve life of the significant number of people with different motor or voice communication disabilities or with completely paralyzed voluntary muscles, which are caused by degenerative diseases or accidents.

Brain-computer interfaces have the potential to build up new communication interface for assistive technologies, including wheelchair control, environment control, various smart home assistive applications or control of personal computers and software applications including web browsers, typewriters, computer spellers or computer games [1][2][3][4].

BCIs are often focused on neuroprosthetics applications that are aimed at repair and restoration of damaged hearing, sight or movement. It can be seen as the part of the narrower class of neuroprosthetics, because of brain-computer interface definition, based on the requisite of the direct connection between neuroprosthesis and the central nervous system (CNS). BCIs can be considered as the part of neurorehabilitation tools because of the neural plasticity of human brain [5].

Crossing the boundaries of medical applications, brain-computer interfaces can be used for smart home applications intended as the enhancements of life quality and have been evaluated as the interfaces that allow control of various equipments including mobile robots, robotic arms, flying drones or as the interfaces that allows driving a car [6].

Attention is paid to the possibility to use it as the new user interface of personal computer and entertainment industry is evaluating the potential of the use in recreation including various forms of computer games and virtual reality applications [7][8].

Potential of brain computer interfaces in robotics is evaluated and different mobile robots are experimentally equipped with this interface and as the example of this effort can be seen humanoid robot Honda Asimo as shown in Fig. 1.

Fig. 1 Brain-Computer Interface used for control of humanoid robot Honda Asimo only with human thoughts. Source: Honda

II. BRAIN-COMPUTER INTERFACE

Brain-computer interface (BCI) or mind-machine interface (MMI) or brain-machine interface (BMI) is the human-machine interface (HMI) that can be defined as the system able to translate subject's intent or thoughts into the technical control signals without the use of the communication channel based on the use of the speech or any other neuromuscular activity.

BCI is building direct communication pathway between the human brain and the computer or external technical device in general with aim to build one-way or two-way communication interface.

The key components of the brain-computer interface systems are data acquisition hardware that is based on the monitoring of signals produced as the manifestation of normal activity of the central nervous system, especially the brain, and the software component that is used for analysis of acquired signals and is extracting features that can be translated into the technical control signals appropriate for use in control of the computer or other external technical device.

Brain-computer interfaces are forming three main groups according to their invasivity to the body of the subject.

A. Invasive Brain-Computer Interface

Invasive brain-computer interfaces are surgically implanted directly into the brain, and are often based on the use of arrays of microelectrodes implanted into the motor or visual cortex. Invasive brain-computer interfaces are able to provide best temporal and spatial resolution of signals. Despite the fact that invasive techniques provide fast and potentially rich information, there are some significant drawbacks. Some of them require implantation into the gray matter of the brain which may lead to infection or permanent tissue damage [9].

B. Partially Invasive Brain-Computer Interface

Partially invasive brain-computer interfaces are locating sensors, often represented by arrays of microelectrodes inside the skull of the subject, but not inside the brain. Electrocorticography (ECoG) is the example of this technique, as shown in Fig. 2.

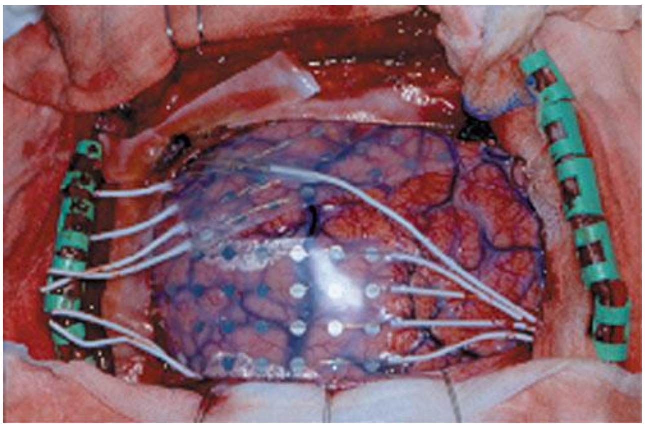

Fig. 2 Electrocorticography (ECoG). Source**:** Dr. Eric C. Leuthardt, Washington University

C. Non-Invasive Brain-Computer Interface

Non-invasive brain-computer interfaces are based on the functional brain imaging techniques, mostly on multi-channel electroencephalography (EEG).

Although non-invasive BCIs are providing the lowest accuracy in the signal acquisition, because of the deflection caused by the subject's skull, there is very important advantage in no modification of the body of the subject and there is also minimal discomfort for the user of the interface.

It is possible to implement non-invasive brain-computer interfaces under the most naturalistic conditions of use with minimal need of the wearable hardware and with advantage of wireless connection to the host computer that is analyzing and transforming signals or to the technical device that is controlled with use of the brain-computer interface.

III. BRAIN IMAGING TECHNIQUES

The key component of the BCI is the data acquisition hardware intended for monitoring of the manifestation of normal neural activity of the central nervous system, especially the brain.

Data acquisition in non-invasive brain-computer interface is based on the brain imaging and this category includes various techniques that are capable directly or indirectly image the structure (structural brain imaging) and function (functional brain imaging) of the subject's brain.

A. Structural Brain Imaging

Structural brain imaging deals with the imaging of the brain structure and there is possibility to use it for diagnostic purpose in the case of intracranial diseases including tumors and in case of various injuries.

Computed Tomography (CT) or Computerized Axial Tomography (CAT) uses series of x-ray images of the head taken from various directions and creates cross-sectional images of the brain.

Magnetic Resonance Imaging (MRI) uses magnetic fields and radio waves to acquire data for formation of two- or three-dimensional images of the brain. MRI has advantage in no use of ionizing radiation or radioactive tracers.

B. Functional Brain Imaging

Functional imaging of the brain is used for diagnostic purpose in case of metabolic diseases and lesions and it is also suitable group of techniques that can be used for neurological and cognitive psychology and for the creation of brain-computer interfaces.

Positron Emission Tomography (PET), using trace amounts of short-lived radioactive materials, Single Photon Emission Computed Tomography (SPECT) (Fig. 3), using gamma-ray emitting radioisotopes, functional Magnetic Resonance Imaging (fMRI) and Near Infrared Spectroscopic Imaging (NIRSI) are techniques that measure and localize changes in cerebral blood flow, which are related and indicate the neural activity of the brain and it is possible to use it for identification of regions of the brain, which are activated when the subject is performing particular tasks.

Other imaging techniques, including the magnetoencephalography (MEG) used for both research and clinical purposes, electrocorticography (ECoG) and electroencephalography (EEG) are suitable techniques for recording of changes in electrical currents and magnetic fields, which are produced as the manifestation of the normal function of the brain.

Electroencephalography (EEG) can be defined as the measurement of the electrical activity of the brain, realized by recording of electrical signals scanned by electrodes, which are placed on the scalp.

The result of measurement, which is called electroencephalogram (EEG), represents the set of electrical signals scanned from large groups of neurons. This technique is frequently used in research and development aimed at creation of the BCI, because the process of its use is non-invasive for the user. Another advantage is that the EEG is capable of high temporal resolution with measurement of electrical activity of the brain on the level of milliseconds.

All of described techniques have its limitations and differ in various advantages and disadvantages. For example MEG or EEG, which measure neural activity of the brain with high temporal resolution, are limited in ability of the spatial resolution and fMRI with its high capability of the localization of the neural activity of the brain has the disadvantage because of its lower temporal resolution.

Fig. 3 Single Photon Emission Computed Tomography (SPECT)
Source: Siemens

IV. EMOTIV EPOC NEUROHEADSET

In our effort to build novel application of the brain-computer interface we are using low-cost commercially available 14 channel EEG hardware Emotiv EPOC Neuroheadset (Fig.4), which is used for acquisition of raw data from electrodes that are positioned at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8 and AF4 positions, according to the international 10-20 system.

Fig. 4 Low-cost EEG signal acquisition hardware Emotiv EPOC Neuroheadset

Odd numbers of electrodes are reserved for the left hemisphere of the brain; even numbers of electrodes are reserved for the right hemisphere of the brain.

Electrodes AF3, AF4, F3, F4, F7 and F8 are used for imaging of neural activity of the lobus frontalis of the subject’s brain. Electrodes FC5, FC6, T7 and T8 are scanning the lobus temporalis of the brain. The lobus parietalis is scanned by P7 and P8 electrodes. Neural activity of the lobus occipitalis is scanned with use of the O1 and O2 electrodes (Fig. 5).

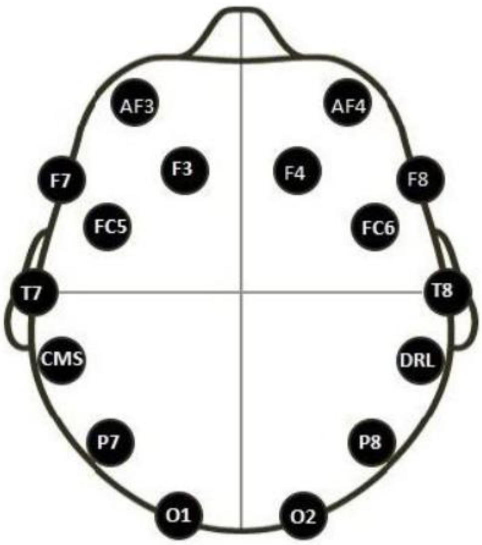

Fig. 5 Electrodes acquiring signals of neural activity of the brain are positioned according to the 10-20 model.

Two referencing electrodes CMS (on the left side) and DRL (on the right side) are used for reduction of the noise in signal.

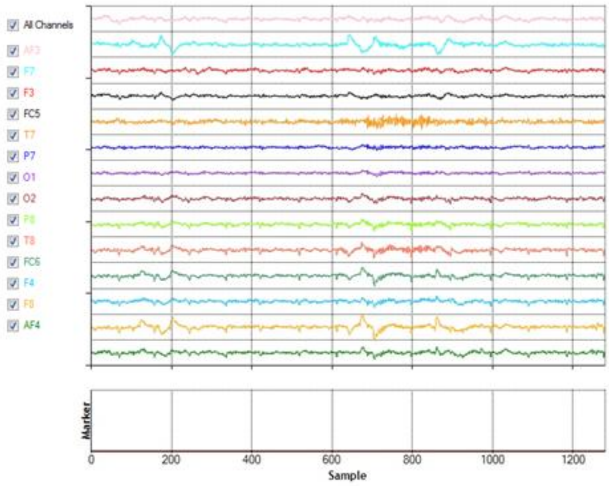

Fig. 6 Characteristic patterns in EEG signals for smile facial expression

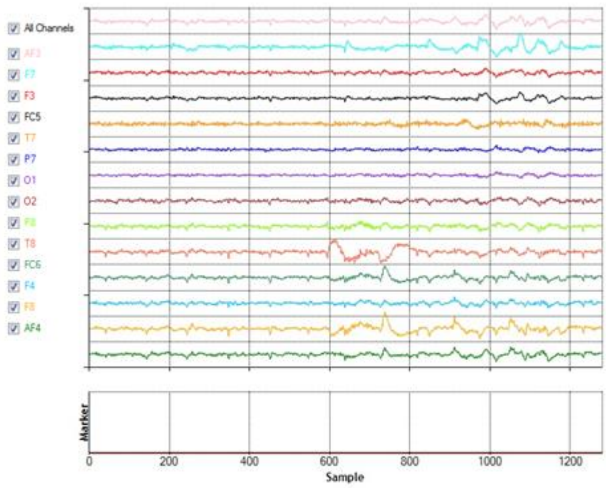

Fig. 7 Characteristic patterns in EEG signals for right smirk facial expression

Signals are sampled with 128 Hz sampling rate and are sent through the wireless connection to the dongle, which is used as a receiver connected to the USB port of the personal computer. Host computer is used to perform computationally expensive analysis of acquired data and transformation into the control signals for software applications.

There is possibility to find characteristic patterns in EEG signals that are connected with facial expressions including blink, right or left wink, right or left look, raise or furrow of brow, smile, teeth clench, right or left smirk and laugh and those patterns are, according to tests provided as the part of our research, recognizable in signals from respective electrodes. (Fig. 6 and 7)

For example, look left or right is manifesting mostly in signals from F7 and F8 electrodes and also in signals from FC5, O2, P8, FC6 and AF4 as shown in Table.1.

Affections of the subject are also manifesting in EEG signals and there is possibility to detect characteristic patterns for engagement, boredom, frustration, meditation, instantaneous excitement or long term excitement, which are connected to the vigilance, alertness, concentration, stimulation, interest, contemplation, expectation or negative feelings.

Intentions of the subject to push, pull, move left, right, up and down and to rotate clockwise, counterclockwise, left, right, forward and backward are also detectable. Intents are connected with real life objects or virtual objects. In case of virtual objects there is possibility to detect intent of the subject to let those objects disappear. The ability to control external technical device is determined by the capability of proper level of concentration of the subject during the process of signal scanning.

Table 1. Recognisability of characteristic patterns of facial expressions in EEG signals.

	Smile	Left smirk	Right smirk	Laugh	Teeth Clench	Look left	Look right	Blink	Left wink	Right wink	Furrow of brow	Rise of brow
AF3	√		√	√	√			√	√	√	√	√
F7	√		√	√	√	√	√	√	√	√	√	√
F3				√	√			√		√	√	√
FC5				√	√	√	√	√	√		√	√
T7	√	√		√	√				√		√	√
P7		√		√	√				√		√	√
O1				√	√							√
O2	√			√	√	√	√					√
P8	√			√	√	√	√					√
T8	√		√	√	√	√	√					
FC6	√		√	√	√	√	√	√		√	√	√
F4	√			√	√			√		√		√
F8	√		√	√	√	√	√	√		√	√	√
AF4	√		√	√	√	√	√	√	√	√	√	√

V. EMO CHESS

Usability of Emotiv EPOC Neuroheadset as the brain-computer interface was researched and demonstrated on the chess game that can be played on the host computer to which Emotiv EPOC Neuroheadset is connected. Description of the requirements and features of the application created for this purpose is subject of the following chapter.

The main requirement was the ability to control the application via the Emotiv EPOC Neuroheadset. Created application should communicate directly with the device, with no need for additional use of software that is part of the Emotiv SDK Tools. Another requirement was graphical user interface for configuration and interconnection of neuroheadset and the game application. The aim was to allow full control of the application via the brain-computer interface with use of the EEG device; however, there was also requirement for traditional way of control through the classical computer interface.

It was important to choose which signals produced by the device will be used and on which kind of control element will be the signal transformed in the host computer. Emotiv EPOC Neuroheadset gives the opportunity to use the gyroscope signals, signals related to the commands based on intensions of the subject and signals related to the commands based on facial expressions. In the host computer it was possible to transform signals from the device into the control signals for the keyboard or for the mouse. The combination of commands based on intensions of the user and control of the mouse was chosen.

As the part of the research in which EmoChess was built, SrcChess, application of the chess game was created and this application is fully operable with the use of computer mouse. Another part of the solution is EmoSharpGUI, the application that handles signals from the neuroheadset and transforms it to the commands for the computer mouse.

The C# was used as the implementation language for the signal processing, combined with the .Net Framework 4.0. Application provides graphical interface for visualization of basic information about the current state of the neuroheadset and received signals. Signals are processed with use of the Emotiv API which consists of ANSI C interface provided in 3 files edk.h, EmoStateDLL.h and edkErrorCode.h and is implementd in 2 Windows DLL – edk.dll and edk_utils.dll.

Emotiv EmoEngine represents logic abstraction of the functionality that provides Emotiv edk.dll. EmoEngine communicates with neuroheadset and receives preprocessed gyroscope and EEG data, manages settings specific for the user and application and transforms detected signals into easy usable data structures.

Data from device are subject of several transformations until they are able to control the cursor of the mouse. Raw data from the device are transformed with use of EmoEngine to the format that is developed for the SDK. EmotivAPI transforms data into the form that can be used in C# and user interface EmoSharpGUI transforms data onto the moves of the cursor with use of WinAPI.

Three modules were created:

- **EmoSharp** – module consists of the basic logic of neuroheadset signals that are processed with use of the Emotiv API.
- **EmoSharpGUI** – module implements graphical interface for visualization of received signals and control of the cursor of the mouse.
- **SrcChess** – module implements the logic of the chess game.

EmoSharpGUI uses the module EmoSharp and implements several program threads:

- *Affectiv* – thread that receives and displays data related to the overall mental state of the user, eg. level of concentration and meditation.
- *Cognitiv* – thread that receives and displays data related to the users mental representations of the movements.
- *Expressiv* – thread that receives and displays the data related to the facial expressions of the user.
- *NeuroheadsetStatus* – thread that receives and displays data related to the status of the neuroheadset eg. battery charge status, status of electrodes, signal strength, strength of the wireless connection signal etc.
- *MouseControl* – thread that is responsible for transformation of signals received from Cognitiv thread to the movements of the cursor of computer mouse.

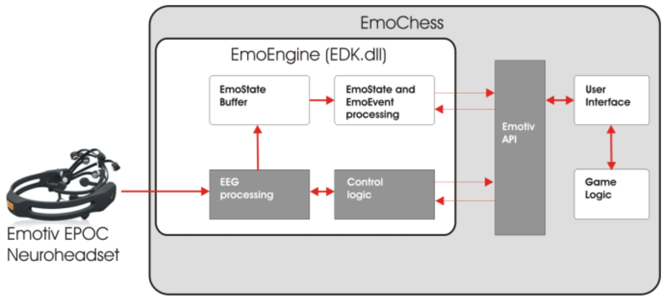

Fig. 8 Model of the signal processing.

CONCLUSION

The paper introduced brain-computer interface as the technology capable of building the communication bridge between central nervous system, especially brain and the computer or other external technical device, with ability to build one-way or two-way communication between the brain and the device. Various application areas of BCIs were also described.

Various techniques of the structural and functional brain imaging with emphasis on the functional brain imaging techniques and especially the multi-channel electroencephalography (EEG) were introduced and also our experience with the low-cost multi-channel EEG neurohardware Emotiv EPOC Neuroheadset was described.

Application that allows playing chess with the use of the brain-computer interface built with the Emotiv EPOC Neuroheadset was created as the part of our research and was introduced in this paper. The aim was to research the possibility to control the complex application with graphical user interface with brain-computer interface. In our research full operability of the application with use of Emotiv EPOC Neuroheadset was confirmed.

In the future research we will focus our attention to the research and development of applications that can be used as the human-machine interface for people with various disabilities with aim to improve their live via various forms of novel assistive technologies.

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