The Architecture of Software Interface for BCI System

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Abstract. The basic idea of Brain Computer Interface (BCI) is the connection of brain waves with an output device through some interface. Aim of this article is to clarify the potential utilization of complex EEG signal in BCI system. For this purpose, the architecture of the software interface was designed and tested. The main task of the interface is to transfer brain activity signal into commands of intelligent robot.

The paper is organized as follows. Firstly, there is a physiological description of the human brain, which summarizes current knowledge and also points out its complexity. The basic principle of BCI system is also explained.

Secondly, the specification of used technical equipment (hardware component and software tools) is provided.

Thirdly, the transfer operation is explained in the description of proposed software interface. Moreover, results of interface tests are also presented.

Finally, discussion deals with the advantages and disadvantages of BCI system and its usage in real-time applications.

Keywords: Electroencephalography, Bran Computer Interface, Robotics, Neuro-headset.

1 Introduction

The human brain is a complex system, which is an object of our research. It is regarded as the most complex system in the universe. The modern science is currently attempting to understand the complex interconnection among individual parts of the brain. [10] There are many publications, which deal with a description of the brain. [1], [3], [10]

The brain itself is composed of several parts, without which his activity could not be possible. One of its basic structural parts is a neuron. The neuronal cells are characterized by the fact that electrical activity is carried out in them. These cells communicate with each other by electrical signals. According to the last estimate, there are approximately 10^{11} neurons in the brain. Every one of them is connected with thousands of other neurons. The main source of Electroencephalography (EEG) signal is an electric activity of synapse - dendrites membrane located in the surface layer of the cortex. Each active synapse dispatches electromagnetic pulse to the environment during excitation. [6] Due to the high number of these pulses, it is difficult to locate their

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source by means of multichannel sensor on the skin. This issue could be compared to full amphitheatre, in which there are chanting people and the task is to recognize from the outside, which specific group of fans shouts. A different perspective on this issue may be such that the aim is to identify a uniqueness of the signal for each individual subject. In the example shown above, it is as we would like to recognize the type of the stadium by the mass of chanting people. For example, there is a noticeable difference between hockey and tennis fans. The biometric signatures are different for each creature on the planet Earth.

Many scientific disciplines deal with the human brain; for example numerical neuroscience, neuroinformatics, informatics or medicine. All of them bring theories, which could explain different brain activities. Numerical neuroscience provides mathematical and biophysical models, which are able to model basic processes in neurons and neural networks. The main goal of neuroinformatics is a systematic development of database intended to collect information such as brain morphology, brain parts anatomy and their functional connection, brain electrophysiology, brain states obtained with magnetic resonance and their integration. Further, it seeks to develop tools for modelling, where the aim is the most accurate emulation of brain activity. In Informatics, complex networks are highly suitable to model a complex system among which the brain includes. The contribution of medicine is undisputable especially in brain anatomy research.

This article deals with the Brain - Computer Interface (BCI) technology, which represents the connection of brain waves with the output device through some interface. Figure 1. illustrate the basic principle of a system based on BCI.

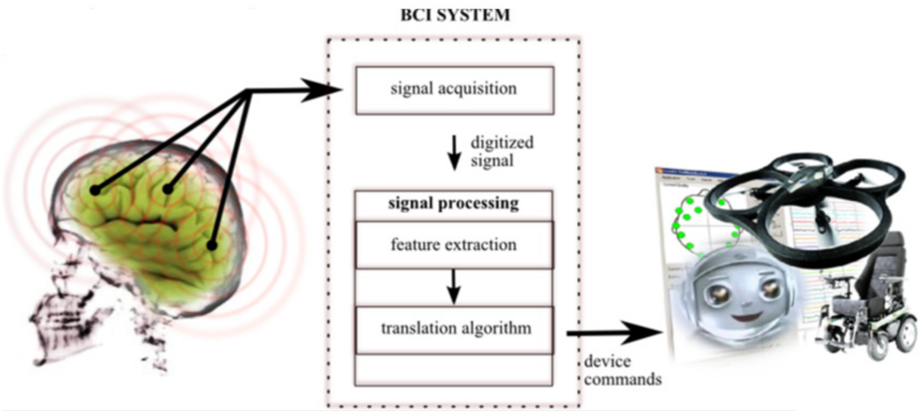

Fig. 1. Basic principle of BCI system

Firstly, the brain activity is obtained from the subject's brain by appropriate device based on some of the technologies, which are currently available for sensing the brain activity; for example fMRI (functional magnetic resonance imaging), EEG (Electroencephalography), ECoG (Electrocorticography) etc. For the purposes of the study described below, EEG technology was chosen to record brain activity.

Further, received signal has to be processed and prepared for translation algorithm. This phase involves a feature extraction during which the most expressive characteristics of obtained signal are discovered. In the case of EEG signal, these characteristics usually relate to some physiological activity such as eye blink, eye movement, raise brow etc.

Finally, the translation algorithm transfers selected features to commands of external device or software.

Currently, there are many known applications of BCI technology, but not enough to each particular field of study. Signal that is sensed from the brain is the key element in the BCI model; therefore the design of an appropriate algorithm for processing of the signal is the most discussed part of BCI model structure. [9]

The aim of this article is to offer an architecture of communication interface between Emotiv EPOC neuro-headset (EEG device) and Mindstorms EV3 (robotic device). Secondary aim was to investigate the reliability of communication between robotic device and neuro-headset.

2 Specification of Technical Equipment

BCI system consists of three main parts: signal sensing, signal processing and external system control. The technical equipment of each part is described separately in the following chapters.

2.1 Signal Sensing

There are several approaches for sensing brain activity. The most widely used is EEG technology, which belongs among the non – invasive methods. Devices based on EEG technology provide signal with very low voltage amplitude because the signal has to pass through the relatively low conductive skull. The amplitude ranges from tens to hundreds microvolts.

Recently, we use Emotiv EPOC neuro-headset to obtain EEG signal from the human brain. Sensing of EEG by Emotiv EPOC neuro-headset has a number of advantages because it already involves solved elementary issues in the processing of the measured signal. Due to this fact, it is not necessary to operate with raw data. It depends on the further usage of the data. Although the spectrum of this data could be used in many applications, it is not simple to understand the entire significance of the whole signal even if the proportion of the noise is minimal. This technology has the greatest expansion and certainly also the priority significance in diagnosis of various diseases in medicine. [1]

Emotiv Corporation developed personal brain - computer interface for human – computer interaction using neuro-technology, which is based on processing of electromagnetic waves occurring in the human brain. The interface has a wide range of possible applications; for example in interactive games, intelligent adaptive environment, audio-visual art and design, medicine, robotics and automotive industry. Moreover, it can be deployed in a large amount of scientific research.

Emotiv EPOC neuroheadset (Figure 2) measures a signal wirelessly transferred to common personal computer. It is a device, which has a set of sensors intended for sensing the activity produced by human brain. Traditional EEG devices requires the use of conductive pasta to improve the conductivity between electrodes and hairs. On the other hand, the neuroheadset do not need any additional tools. It has 14 high resolution sensors, which are placed on optimal positions on the human head (Figure 3).

Fig. 2. Emotiv EPOC neuroheadset [4]

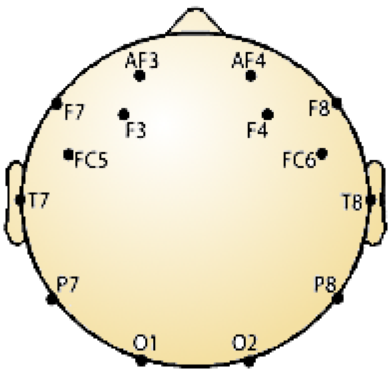

Fig. 3. Placement of electrodes of Emotiv EPOC neuroheadset

Moreover, it also includes gyroscope for determinate the position in the area. Each channel has its own label based on its position on the head: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. Internal sampling frequency of the neuroheadset is 2048 Hz. On the other hand, the neuroheadset provides signal with sampling frequency of 128Hz. More information about neuroheadset can be found in [4].

Emotiv provide basic software set containing many tools, which can be used for recording various signals such as electric potential from all 14 sensors, power spectrum of individual EEG channels in real time and rotational acceleration of the head in horizontal and vertical axis using data from gyroscope. All of these outputs are shown in graphs. Data are also available in raw form, which can be used for further analysis. If it is required special functionality, which is not provided by native software, it is desirable to develop own application using Emotiv SDK (Software Development Kit).

2.2 Signal Processing

Signal processing is important part of BCI system; therefore, this area has to be deeply examined. This part is responsible to either physiological or mental activity recognition. Current recognition methods are able to detect following states of mind:

Instantaneous excitement - introduced as a consciousness or feeling of physiological excitement with positive value. Excitement is characterized by activation of sympathetic nervous system, which is responsible for physiological responses such as dilated pupils, stimulation of the sweat glands, pulse frequency etc.

Long-term excitement - similar to instantaneous excitement. Detection of this state is designed and set to obtain more precise measurement of excitement changes in longer time periods (minutes).

Engagement - known as both alertness and directing attention to suggestions to the tasks. It is characterized as a growth of physiological excitement. It can be observed in beta-waves and alpha waves of EEG record. Contrary of this state is called boredom. The more attention or concentration is performed, the higher value is recorded during detection phase. The writing of text to the paper or writing on computer rises a value of engagement state, while closing eyes almost always rapidly decreases that value.

The most pronounced physiological activity is facial expression; thus, movement of brow, mouth or eyes can be detected. The brain signals of these activities is similar among all people; therefore, universal signatures can be used to detect facial expressions of almost each person.

2.3 External System Control

External system can be either software or hardware model. For the purposes of our research, robotics device Mindstorms EV3 was chosen as an external system (Figure 4.), because it supports most of communication interfaces such as Bluetooth, Wi-Fi, USB connection etc. It consist of many static parts from which it is possible to construct various robotic solutions. Further, robot can be equipped with colour sensor, ultrasonic sensor, gyroscope sensor or touch sensor. Robot's motion is assured by interactive servomotors. Communication and logic of robot's behaviour is controlled by programmable intelligent EV3 Brick. Figure 4. shows an example of one specific robotic device, which is possible to construct from parts described above.

Intelligent EV3 Brick can be programmed in native graphics program language in LabView software. Moreover, there is also an option to develop own software application in some other supported languages such as Java, C# etc.

Fig. 4. Robotic device Mindstorms EV3

3 Results

The whole application interface was realized on the higher abstraction level. Its architecture was designed with emphasis on mutual compatibility among available technical resources.

Parallelization was chosen in order to achieve real time response; thus, proposed application contains special program threads, where individual consuming operations are carried out. Thread B (labelled as Brain part) performs communication with the neuroheadset and listens to events related to physiological activity such as blink of an eye. Thread C (labelled as Computer/device part) was implemented analogously to previous thread, but it is connected to the external system; in our case, it is a robotic device Mindstorms EV3. The main task of thread C is to switch servomotors of a robot according to states, which are transmitted between threads B and C. Time constants for both loops were selected in milliseconds. Finally, Interface part is main thread in which translation algorithm takes care of interconnection between B and C thread. Proposed architecture of communication interface is depicted on Figure 5. Then, whole design and realization with the real devices is a prototype, which has to be subjected to thorough testing on several levels of development. Interface part is main thread of application.

The part of Emotiv research SDK edition software package is also a simulator of brain activity called EmoComposer, which is able to simulate occurrence of brain activities mentioned in previous section of this article. Firstly, the testing of reliability of proposed communication interface were tested using that simulator, which communicates through the same network protocol. At this case, reliability was 100%; thus, each initiation of specific brain activity using the simulator caused a motion of the robotic device. Eye blinking was chosen as test brain activity.

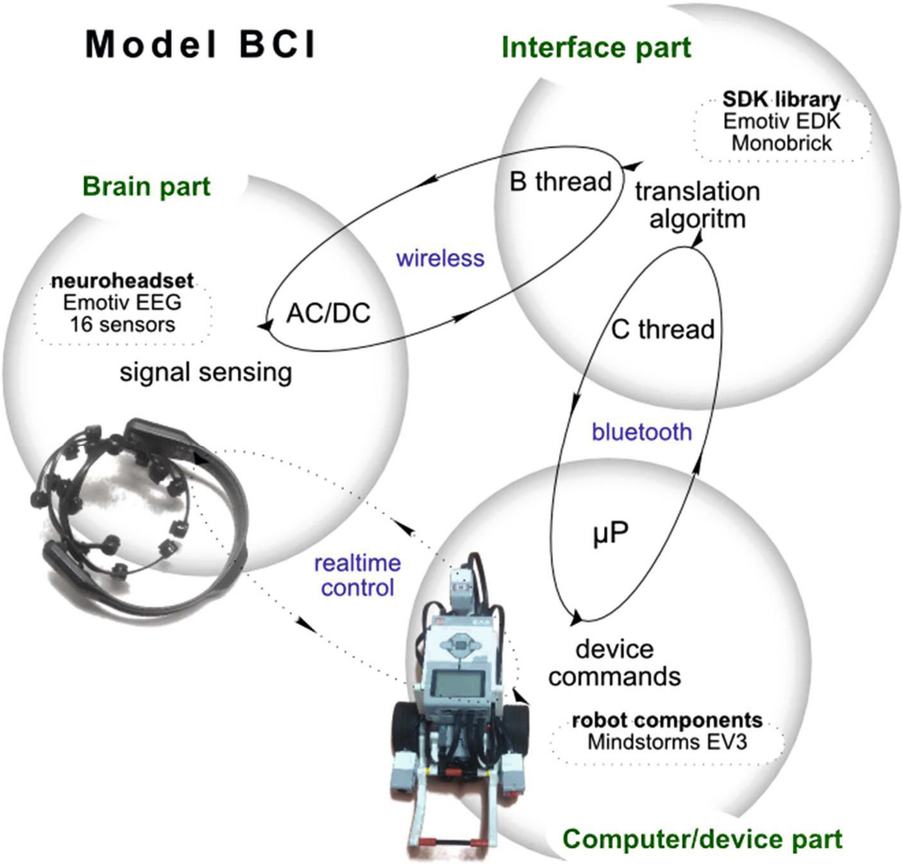

Fig. 5. Architecture of proposed software interface

Experiment with real neuroheadset showed different results. EEG record of eye blinking is depicted in Figure 6, where its activity is bounded by red rectangle. Neuroheadset was set on the head of test subject. Further, the scanned brain activity of the subject was sent to the computer through the wireless connection. Obtained signal was processed using proposed communication interface mentioned above. Finally, an appropriate command was sent to the robotic device. The aim of this experiment was to find out the real efficiency of brain- computer interface when universal signature is used to detect a specific brain activity from the subject.

Eleven individual experiment sets were performed. Table 1. shows the results for each of them. Each set involve certain number of attempts. Whenever a movement of robot appeared after the subject’s eyewink, it was counted as successful attempt. Overall, it was measured 330 attempts. The lowest value of reliability was 0.5 (50%), while the highest value was 0.83 (83%). The average reliability was 0.65 (65%).

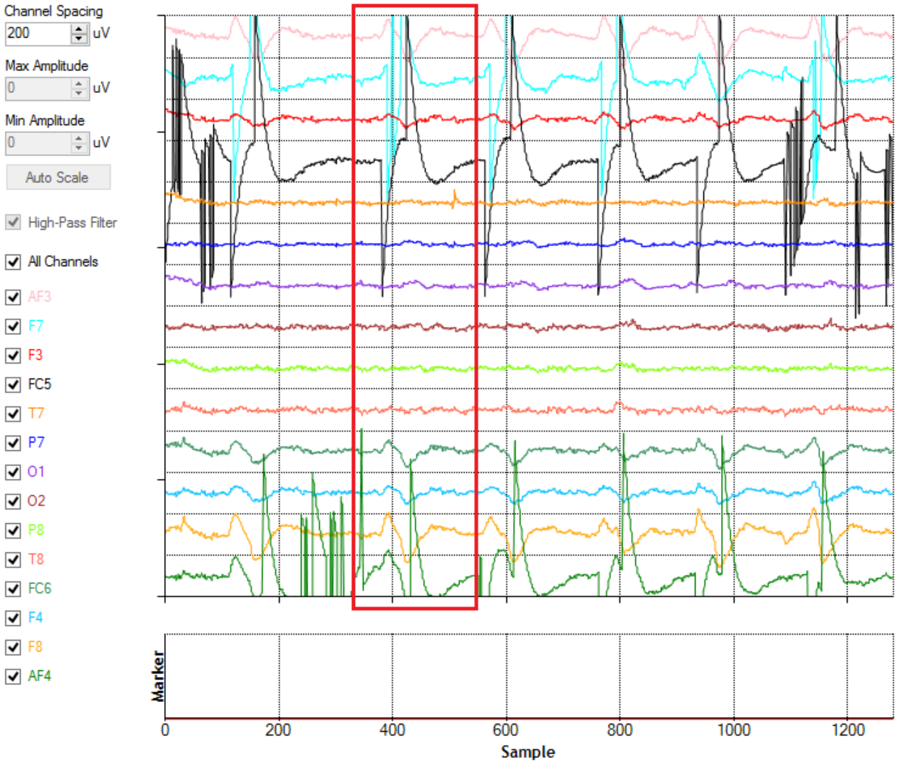

Fig. 6. Example of eye blinking record

Table 1. Reliability of robot response on eye blinking activity

Set ID	Number of attempts [-]	Number of successful attempts [-]	Reliability [%]
1	30	17	56,667
2	30	18	60
3	30	17	56,667
4	40	33	82,5
5	30	25	83,333
6	30	21	70
7	30	18	60
8	30	19	63,333
9	30	15	50
10	20	16	80
11	30	17	56,667

4 Discussions

Human brain is the most complex known system in the universe. Study of its activity is extremely important mainly due to the most precise diagnosis of brain diseases and their treatment. Furthermore, acquired knowledge could be used in modern technologies with BCI systems, where an interaction between brain and computers appears.

Our research deals with BCI system, which was used to control robotic device. We designed the architecture of software communication interface between neuroheadset and robotic equipment. The abilities of proposed software were confirmed on real BCI system. The system consisted of EEG device, computer and a robotic device. Tests proved that proposed architecture of software communication interface meets requirements for real-time control of an external device using brain waves.

Further, our research examined practical issues associated with currently one of the most advanced EEG equipment intended for technical utilization. The time, which one spends with its installation on the subject head, is approximately from 5 to 10 minutes. It depends on whether it is the very first installation of the equipment or whether it is reused in the same day. Even if the device does not need any special gel, which will be applied on subject's head, it still requires application of saline solution on sensor pads. Further, the important part of the installation is also to find the right position for the neuro-headset on the head. This process is usually controlled by software, which provides information about contact quality of each sensor. This issue is not problem in laboratory conditions, but it could bring complications in practical applications; thus, it could be the one of the main reasons of making the whole system unusable because of the time needed to set the system up. On the other hand, current EEG devices provide EEG signal in the highest possible quality depended on the current technical progress.

The aim of our experiment was to demonstrate the real efficiency of communication between EEG and the robotic device using universal signature of selected brain activity. The average reliability of robotic device response on signal of eye blinking was 65.45%. This low reliability could be caused by noise in the electromagnetic signal and different artefacts in biological activities. Moreover, prolonged use of neuroheadset may leads to headache caused by slight pressure of soft pads on the skull; thus, subject's focus on repeating the same activity may be partly affected by this unwanted headache. Finally, it was also the reason for making breaks after each three set of attempts. In addition, inexperienced subject need time to become familiar with how to properly perform an activity, which should be recognized using universal signature. Other investigations shows that even subjects who have no BCI control in the first few sessions can learn the operation by neuro-/biofeedback training. [2], [5], [7], [8]

Our research proved that robot can react on eye blinking activity. The set of universal signatures contains other activities (brow movement, smile etc.). Each of them could be mapped into different robot action. Unfortunately, there are many activities, which are not included in the set of universal signatures e.g. movement imagination, limb movement etc. These activities can currently be recognized only after additional learning of neural network. This kind of activities could be another appropriate subject of further research.

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References

1. Adeli, H.: Wavelet-Chaos-Neural Network Models for EEG-Based Diagnosis of Neurological Disorders. In: Kim, T.-H., Lee, Y.-h., Kang, B.-H., Ślęzak, D. (eds.) FGIT 2010. LNCS, vol. 6485, pp. 1–11. Springer, Heidelberg (2010)
2. Birbaumer, N., Ghanayim, N., Hinterberger, T., Iversen, I., Kotchoubey, B., Kübler, A., Perelmouter, J., Tuab, E., Flor, H.: A spelling device for the paralysed. Nature 398(6725), 297–298 (1858), doi:10.1038/18581 (cit. February 23, 2015)
3. Damasio, H.: Human brain anatomy in computerized images, 303 p. Oxford University Press, New York (1995) ISBN 0195082044
4. Emotiv | EEG System | Electroencephalography (2012), `http://www.emotiv.com/index.php`
5. Guger, C., Edlinger, G., Harkam, W., Niedermayer, I., Pfurtscheller, G.: How many people are able to operate an eeg-based brain-computer interface (bci)? IEEE Transactions on Neural Systems and Rehabilitation Engineering 11(2), 145–147 (2003), doi:10.1109/tnsre.2003.814481 (cit. February 23, 2015)
6. Kandel, E.R., Schwartz, J.H., Jessell, T.M.: Principles of neural science, 4th edn., vol. xli, 1414 p. McGraw-Hill, Health Professions Division, New York (2000) ISBN 978-0-8385-7701-1
7. Neuper, C., Schlögl, A., Pfurtscheller, G.: Enhancement of Left-Right Sensorimotor EEG Differences During Feedback-Regulated Motor Imagery. Journal of Clinical Neurophysiology 16(4), 251–261 (1999), doi:10.1007/978-4-431-30962-8_23 (cit. February 23, 2015)
8. Pfurtscheller, G., Guger, C., Müller, G., Krausz, G., Neuper, C.: Brain oscillations control hand orthosis in a tetraplegic. Neuroscience Letters 292(3), 211–214 (2000), doi:10.1016/s0304-3940(00)01471-3 (cit. February 23, 2015)
9. Schalk, G., McFarland, D.J., Hinterberger, T., Birbaumer, N., Wolpaw, J.R.: BCI2000: A General-Purpose Brain-Computer Interface (BCI) System. IEEE Transactions on Biomedical Engineering 51(6), 1034–1043 (2004), doi:10.1109/tbme.2004.827072 (cit. February 23, 2015)
10. Sporns, O., Tononi, G., Kötter, R.: The Human Connectome: A Structural Description of the Human Brain. PLoS Computational Biology 1(4) (2005), doi:10.1371/journal.pcbi.0010042 (cit. February 23, 2015)