USING BRAIN - COMPUTER INTERFACE FOR CONTROL ROBOT MOVEMENT

Jaromir Svejda, Roman Zak, Roman Senkerik and Roman Jasek
Department of Informatics and Artificial Intelligence
Tomas Bata University in Zlin
Nam T.G. Masaryka 5555, 760 01 Zlin, Czech Republic.
E-mail: {svejda, rzak, senkerik, jasek}@fai.utb.cz

KEYWORDS
Electroencephalography, Brain - Computer Interface, Robotics, Neuro-headset

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, real application of BCI technology was designed and tested. This paper describes this real application in detail and discussed its qualities with respect to its further practical utilization.

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 (Sporns et.al. 2005). There are many publications, which deal with a description of the brain. (Adeli 2010, Damasio 1995, Sporns et al. 2005)

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. (Kandel et al. 2000) Due to the high number of these pulses, it is difficult to locate their source by means of multichannel sensor on the skin. 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. illustrates the basic principle of a system based on BCI.

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) 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.

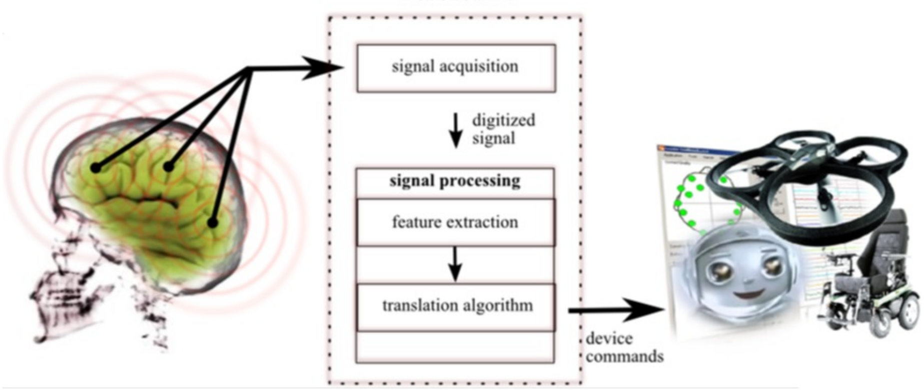


Figure 1: Basic principle of BCI system

Proceedings 29th European Conference on Modelling and Simulation ©ECMS Valeri M. Mladenov, Petia Georgieva, Grisha Spasov, Galidiya Petrova (Editors)
ISBN: 978-0-9932440-0-1 / ISBN: 978-0-9932440-1-8 (CD)

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. (Schalk et al. 2004)
The aim of this paper is to introduce a real application of BCI technology which uses Emotiv EPOC neuro-headset (EEG device) for sensing brain activity and robotic device Mindstorms EV3 as an external device.

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.

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. (Adeli 2010)
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 neuro-headset (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 neuro-headset do not need any additional tools. It has 14 high resolution sensors, which are placed on optimal positions on the human head (Figure 3).

Figure 2: Emotiv EPOC neuro-headset (Emotiv 2012)

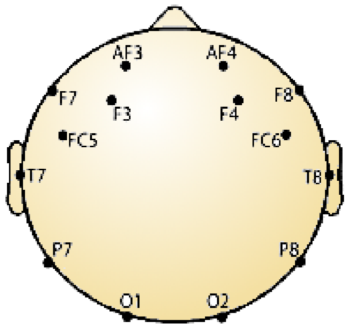


Figure 3: Placement of electrodes of Emotiv EPOC neuro-headset

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 neuro-headset is 2048 Hz. On the other hand, the neuro-headset provides signal with sampling frequency of 128Hz. More information about neuro-headset can be found in (Emotiv 2012).
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).

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 based on artificial neural networks and they 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.

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.

Figure 4: Robotic device Mindstroms EV3

RESULTS

The structure of proposed BCI application can be divided into three parts as was described in previous section: signal sensing, signal processing and external system control.

Signal sensing part ensures measurement of brain signals using Emotiv EPOC neuro-headset. Moreover, data from embedded gyrocope are also recorded. Both brain signal and gyroscope data are sent to the computer through the wireless connection. Further, obtained data are processed in software application interface.

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 neuro-headset and listens to events related to physiological activity such as blink of an eye; it also receives gyroscope data. 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 delay for both loops were selected in hundreds of milliseconds to ensure fluent communication between neuro-headset and robot. Moreover, when one of the servomotors is started by communication interface, it requires at least 100ms to perform required operation.

Gyroscope has to be calibrated before its usage. That operation takes 550ms. The data from gyroscope is then used to control direction of robot rotation. Even if the data contains values of angular velocity in horizontal (x) and vertical (y) axis, robot is controlled with using only horizontal movement of neuro-headset, where the gyroscope is located. Robot control is performed as follows. Whenever neuro-headset rotates left, robot also rotates to left. The same applies for right rotation. Moreover, software interface is set to react on angular velocity higher then 20 deg/s in both directions. The reason for this adjustment was too high sensitivity of control due to which the robot was difficult to control.

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 6. 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. Activity of open eye was chosen as test brain activity. Gyroscope could not be simulated, so it was tested with real devices.

Experiment with real neuro-headset showed following results. EEG record of closed eyes is depicted in Figure 5, where its activity is bounded by red rectangle. The rest of the signal responds to the state of open eyes. Neuro-headset 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 of open eyes state is used to detect a brain activity from the subject.

Current study builds on our previous research, which dealt with the EEG signal analyses with respect to its usage for biometrical purposes. (Zak et al. 2014, Svejda et al. 2014) Our previous research brought results of response reliability on universal signature of eye blinking activity. The model reacts with approximately from 60 to 70% success rate. However, current research showed that universal signature of open or close eyes is more suitable; the succes rate was around 98%.

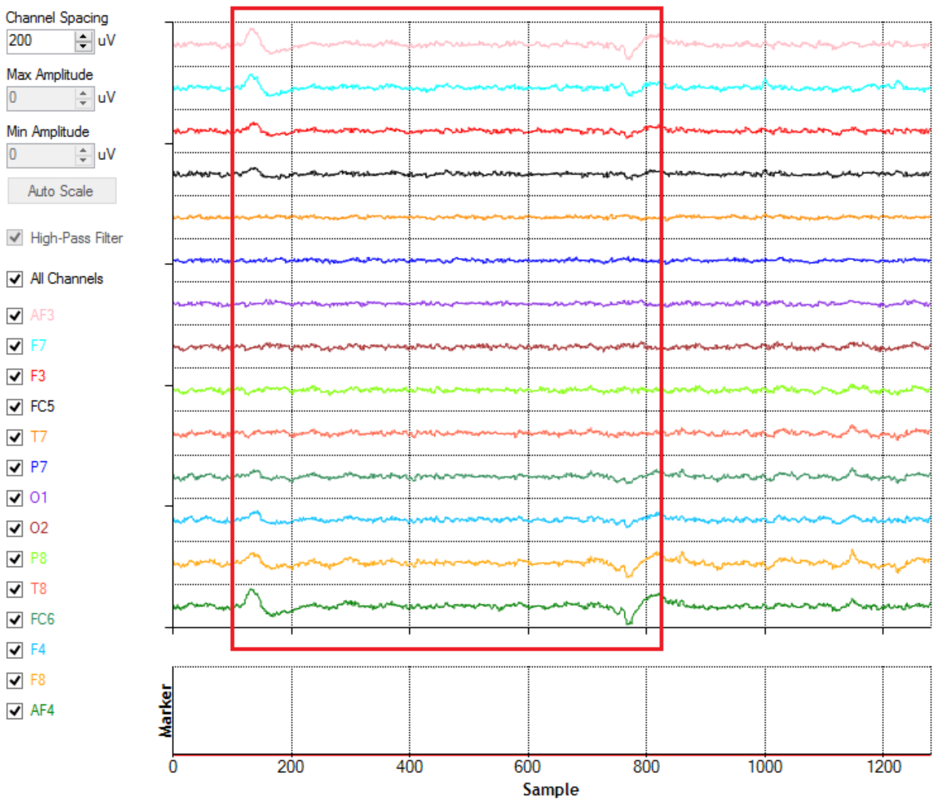


Figure 5: Example of close eyes record (bordered by the red line) and open eyes record (not bordered)

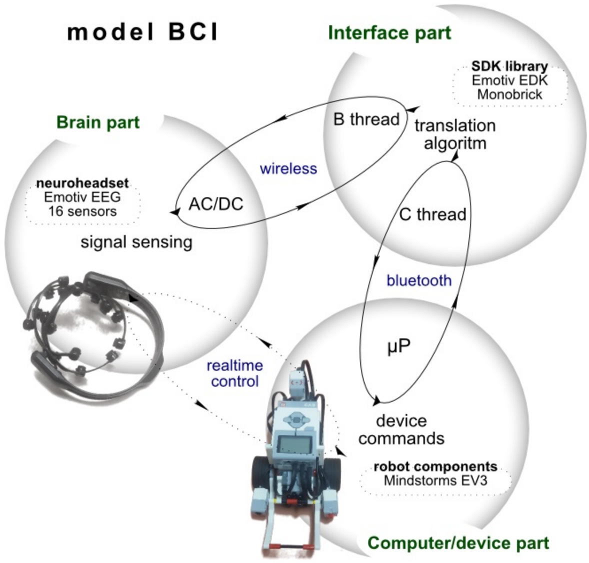


Figure 6: Architecture of described software interface

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 neuro-headset 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 signatures of selected brain activities. The average reliability of robotic device response on signal of eye blinking was 65.45%. On the other hand, the response on state of open eyes was around 98%. Therefore, we decided to use universal signature of open eyes in our further research. These results were obtained during initial test experiment, whose aim was to find out whether it is possible to use brain activity signal to control external device; therefore, only one volunteer was participated in this initial experiment. There were performed 300 attempts of eye blinking activity detection with this participant. Our future research will deal with proving of mentioned results on greater group of volunteers.

The low reliability could be caused by prolonged use of neuro-headset which 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.

Further, difference between response reliabilities on two selected brain activities could be caused by the different difficulty level of tested tasks. Repeating the eye blinking activity with respect to obtain similar signal waveform at each attempt seems to be more complicated then repeating state of open/close eyes. Moreover, the first activity has usually short duration, while the second may be quite longer; thus, it brings more comfort ways to control external device.

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. (Birbaumer et al. 1999, Guger et al. 2003, Neuper et al. 1999, Pfurtscheller et al. 2000)

Our research proved that robot can react on brain 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.

ACKNOWLEDGEMENTS

This work was supported by Internal Grant Agency of Tomas Bata University under the project No. IGA/FAI/2015/063, further by Grant Agency of the Czech Republic - GACR P103/15/06700S, further by financial support of research project NPU I No. MSMT-7778/2014 by the Ministry of Education of the Czech Republic and also by the European Regional Development Fund under the Project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089.

REFERENCES

Adeli, H. 2010. 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) Future Generation Information Technology, vol 6485. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp 1-11. doi:10.1007/978-3-642-17569-5_1.

Birbaumer, N., N. Ghanayim, T. Hinterberger, I. Iversen, B. Kotchoubey, A. Kübler, J. Perelmouter, E. Tuab and H. Flor. 1999. A spelling device for the paralysed. Nature [online]. vol. 398, issue 6725, s. 297-298. DOI: 10.1038/18581.

Damasio, Hanna. 1995. Human brain anatomy in computerized images. New York: Oxford University Press, 303 p. ISBN 0195082044.

Emotiv | EEG System | Electroencephalography. 2012. (online). Available from: http://www.emotiv.com/index.php.

Guger, C., G. Edlinger, W. Harkam, I. Niedermayer and G. Pfurtscheller. 2003. How many people are able to operate an eeg-based brain-computer interface (bci)?. IEEE Transactions on Neural Systems and Rehabilitation Engineering [online]. vol. 11, issue 2, pp. 145-147. DOI: 10.1109/tnsre.2003.814481.

Kandel, Eric R., James H. Schwartz and Thomas M. Jessell. 2000. Principles of neural science. 4th ed. New York: McGraw-Hill, Health Professions Division, xli, 1414 p. ISBN 978-0-8385-7701-1.

Neuper, C., A., Schlögl and G., Pfurtscheller. 1999. Enhancement of Left-Right Sensorimotor EEG Differences During Feedback-Regulated Motor Imagery. Journal of Clinical Neurophysiology [online]. vol. 16, issue 4, pp. 251-261. DOI: 10.1007/978-4-431-30962-8_23.

Pfurtscheller, G., C. Guger, G. Müller, G. Krausz and C. Neuper. 2000. Brain oscillations control hand orthosis in a tetraplegic. Neuroscience Letters[online]. vol. 292, issue 3, pp. 211-214. DOI: 10.1016/s0304-3940(00)01471-3.

Schalk, G., D.J. McFarland, T. Hinterberger, N. Birbaumer and J.R. Wolpaw. 2004. BCI2000: A General-Purpose Brain-Computer Interface (BCI) System. IEEE Transactions on Biomedical Engineering [online]. vol. 51, issue 6, pp. 1034-1043 DOI: 10.1109/tbme.2004.827072.

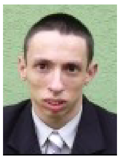
Sporns, O., G. Tononi and R. Kötter. 2005. The Human Connectome: A Structural Description of the Human Brain. PLoS Computational Biology[online]. vol. 1, issue 4. DOI: 10.1371/journal.pcbi.0010042.

Svejda, J., R. Zak, R. Senkerik and R. Jasek. 2014. Complex Analysis of EEG Signal for Biometrical Classification Purposes. Proceedings of Nostradamus 2014 – Prediction, modeling and analysis of complex systems, pp. 449 - 459. DOI: 10.1007/978-3-319-07401-6_45.

Zak, R., J. Svejda, R. Senkerik and R. Jasek. 2014. Analysis of EEG signal for using in biometrical classification (2014) Proceedings - 28th European Conference on Modelling and Simulation, ECMS 2014, pp. 377 - 381.

AUTHOR BIOGRAPHIES

JAROMIR SVEJDA was born in the Czech Republic, and went to the Tomas Bata University in Zlin, where he studied Information Technologies and obtained his MSc degree in 2011. He is now a Ph.D. student at the same university. His email address is: svejda@fai.utb.cz.



ROMAN ZAK was born in the Czech Republic, and went to the Tomas Bata University in Zlin, where he studied Information Technologies and obtained his MSc degree in 2011. He is now a Ph.D. student at the same university. His email address is: rzak@fai.utb.cz.

ROMAN SENKERIK was born in the Czech Republic, and went to the Tomas Bata University in Zlin, where he studied Technical Cybernetics and obtained his MSc degree in 2004, Ph.D. degree in Technical Cybernetics in 2008 and Assoc. prof. in 2013 (Informatics). He is now an Assoc. prof. at the same university (Research and courses in: Applied Informatics, Cryptology, Artificial Intelligence, Mathematical Informatics). His email address is: senkerik@fai.utb.cz.

ROMAN JASEK is working as a Associate Professor, head of Department of Informatics and Artificial Intelligence in Faculty Applied Informatics in Tomas Bata University in Zlin. He graduated from computer science in Palacky University in Olomouc, his Ph.D. received in Charles University in Prague. His research interests are: Artificial Intelligence, Computer Science and Data Security. His email address is: jasek@fai.utb.cz.