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BRAIN-COMPUTER INTERFACE FOR MOBILE DEVICES

The article presents the results of research in controlling the mobile application with the EEG signals and eye blinking. Authors proposed a prototype solution of a brain-computer interface that can be used by people with total motor impairment to control chosen mobile application on their mobile phone. There was a NeuroSky MindWave Mobile device used during experiments. Two software tools for mobile devices were specially implemented. First one helps to analyse the EEG signals and recognize eye blinks, second one - interprets them and executes assigned actions. Different configurations of settings were used during the studies. They included: single blink or double blink, level of focus, period of focus. Experiments results show that a man equipped with a personal EEG sensor and eye blinking detector can remotely touchless use mobile applications installed on smartphones or tablets.

1. INTRODUCTION

1.1. HUMAN-COMPUTER INTERFACES

Over the years people have been using many different approaches of interaction with machines. Standard and basic physical interfaces for computers are keyboard and mouse. Besides these interfaces, people also invented alternative solutions. One of them is touch screen technology. Nowadays this technology uses capacitive sensing of human body, particularly skin on user's fingertip. All above technologies are based on physical interaction with devices and controllers.

There are also other ways of establishing connection between human and machine or computer system. What is interesting, interaction with computers can be achieved without touching anything. One of these technologies is Kinect developed by Microsoft for the Xbox 360 video game console. Kinect is a motion sensing input device containing RGB camera, depth sensor and multi-array microphone running proprietary software, which provides full-body 3D motion capture, facial recognition and voice recognition capabilities. It can be called simply a natural user interface. Kinect competes with another approach called Wii and a few PlayStation controllers, which are based on similar concepts. This way of communication can be considered as another human-computer touchless interface.

Human-Computer Interaction (HCI) researchers explore possibilities that allow computers to use as many sensors channels as possible [22]. Most of the concepts mentioned above, require

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some kind of action from human being. There are also people with strongly limited possibilities caused by illnesses, diseases and disabilities. Part of them is partially paralysed. For such kind of people present technology is unfortunately inaccessible. This barrier could be overcome by Brain-Computer Interface (BCI) also known as Mind-Machine Interface (MMI) or Brain-Machine Interface (BMI), which is direct pathway between brain and an external device.

1.2. THE AIM OF THE PROJECT

The aim of the project was to propose useful BCI, which would allow users with motor disabilities to use simple smartphone functionality with electrical activity of the user's brain. The electroencephalographic (EEG) devices mostly measure such human activity states as attention or relaxation, and sometimes eye blinks. These kinds of signals can be used to control a mobile device. Recorded signals can be sent via Bluetooth to a mobile application. By achieving focus state over predefined level, the user is able to choose appropriate option and perform basic operations like phone call, sending SMS, e-mail with predefined text or play voice message.

2. RELATED WORKS

In the recent years, a great number of BCI systems have been developed to provide an alternative communication tool for people with severe neuromuscular disorders. Hundreds of BCI research articles were publicized describing development or improvement of methodologies for signal processing, development of new BCI paradigms or improvement of existing BCI paradigms, investigations of factors influencing the performance of BCI systems, and practical applications of BCI technologies [6]. A lot of BCI applications implemented, are associated with different areas, i.e.: mental speller [2], [7], [23] mouse control [15], [20], robot arm control [3], [5], [25], game applications [14], [17], navigation [21], drowsiness detection system [9], a brain-controlled smart home system [11], cognitive ability assessment system [19], etc. Finally, also BCI mobile phone applications have been developed.

One of the first mobile applications used a wireless EEG headband prototype with 4 electrodes targeting non-hairy skin area of the forehead [10]. This project connects neural signals to mobile phones to display visualization and for simple analysis of the signal. However the mobile device was used as a mobile display and not as a phone.

Another wearable and wireless EEG system with a mobile phone consisting a four-channel bio-signal acquisition module was used to directly make a phone call [24]. During experiments, examined persons inputted 10-digit phone numbers. The NeuroPhone system [1] that allows neural signals to drive mobile phone applications on the iPhone using wireless Emotiv EPOC EEG headset is very interesting [4]. A brain-controlled address book dialing application works on similar principles to P300-speller [12] brain-computer interfaces. The smartphone presents several photos of contacts from the address book and a P300 brain potential is elicited when the flashed photo matches the person whom the user wishes to dial. His or her phone number is automatically dialed.

3. RESEARCH ENVIRONMENT

3.1. NEUROSKY MINDWAVE MOBILE

The first step during preparation phase of the project was the decision on the selection of BCI hardware that will be used in the research. Existing comparison of the most popular

EEG devices [18] does not contain all available devices and does not include medical devices. However medical devices are usually more advanced, more accurate, not portable and very expensive. Most of the consumer EEG devices are affordable for an average user. Lot of these devices use Bluetooth as a communication interface and can interact with computer or other wireless devices (i.e. mobile phones). Some of the older versions of BCI devices use radio communication instead of Bluetooth. Most devices have one electrode, which is enough for many applications, but there are also more advanced and more expansive devices with greater number of electrodes used for measuring brain waves, i.e. Emotiv EPOC. This headset has 14 data collecting electrodes and 2 reference electrodes.
The another one of consumer BCI devices is NeuroSky MindWave Mobile [16]. Devices developed by this producer are affordable, work quite well and have their own Software Development Kit (SDK), so software developers can easily create own applications. NeuroSky Mindwave Mobile is also quite cheap device with good measurement accuracy, which can result in a wider group of potential users. These reasons influenced the choice of this device for experiments.
The NeuroSky system consists of dry electrodes and a specially designed electronic circuit. The device consists of a headset, an ear-clip, and a sensor arm (Fig. 1). The headset's reference and ground electrodes are on the ear clip and the EEG electrode is on the sensor arm, resting on the forehead above the eye. The MindWave Mobile safely measures and outputs the EEG power spectrums (alpha waves, beta waves, etc.). Also blink strength value was measured with EMG sensor included in NeuroSky device. Headset of MindWave Mobile transfers data via Bluetooth.

Fig. 1. Neurosky MindWave Mobile device.

NeuroSky MindWave has been compared with Biopac system, a well-known wet electrode EEG system widely used in medical and research applications. EEG was recorded for various conditions such as with the subject relaxing and in a meditative state, alert and in an attentive state, and during eye blinks artifacts. The results show that differences between measurements of Biopac and NeuroSky Mobile are very small and acceptable.

3.2. THINKGEAR - APPLICATION PROGRAMMING INTERFACE

ThinkGear is a software library for interaction with NeuroSky Mobile devices. NeuroSky Mobile needs to be connected to any external device. It can be a desktop computer, server, microcontroller, mobile phone, tablet or any device, which supports Bluetooth connection.

ThinkGear communications driver consists of shared files: .dll, .bundle or .jar depending on the programming language. A programmer has to call functions from the shared library. The following programming languages are supported: C, C++, C#, Objective C, Java or any language that can call shared library functions. Projects created for the experiments is dedicated for Android platform, so library necessary for development of the applications for this platform should be described in details.

In order to create mobile Android application in Java language using MindWave mobile, it is necessary to use ThinkGear library compiled into .jar file. After attaching this library to a specific project, developers can create application utilizing ThinkGear technology. The mentioned library and sample source code can be downloaded from the official NeuroSky website.

Typically, real time EEG signal processing and classification algorithms are designed for powerful machines. Some of them use a weighted combination of various classifiers for EEG classification [13]. Mobile phones have limited resources and lower power efficiency, so it is impossible to implement them and run in form of mobile application. However, the ThinkGear Android API reduces the complexity of managing connections and handles parsing of the data stream from the EEG headset. This comfortable software interface supplies both raw data and pre-processed data. The Software developer receives the value of concentration and relaxation normalized to the range 0-100%. Movement of muscles responsible for blinking of the eye is normalized in the same way. It is very convenient and helps avoid raw data analysis. To implement a brainwave-sensing application, all that is needed is to import a library, add the requisite setup and teardown functions, and create a handler object to which accessory event notifications will be dispatched.

3.3. PROTOTYPE SOFTWARE TOOLS

3.3.1. EEG ANALYSER

Existing mobile applications for NeuroSky MindWave don't provide function of data export, what is important for further analysis. Our first application is called EEG Analyzer and utilizes basic functionalities of the EEG technology and MindWave Mobile device. It is responsible for reading EEG data from MindWave Mobile and presenting them in a textual and graphical form (Fig. 2). It can also record EEG data, export it, and transfer it to the DropBox account for further analysis. Object oriented source code of EEG Analyzer is the core and basis for the EEG Controller - next applications directly used in experiments. The EEG Analyzer was used to analyze brain activity of the examined person. It is important, because such measurement can give information, how attention and meditation level is changing over the time. It can be a very good input for the further investigation and creating prototype solutions. Mentioned measurement was performed with EEG Analyzer. The data was exported to *.csv file and transferred to Dropbox server, from which it could be downloaded for further analysis. The application measured attention level, meditation level and blink strength during the time. Time of measurement was 631 seconds (approximately: 10.5 minutes). The data presenting attention level, meditation level and blink strength was recorded at the same time.

3.3.2. EEG CONTROLLER

The second prototype application is called EEG Controller. Its intention is to be real Brain Computer Interface for mobile devices. With using this application the user can send e-mails and short text messages from predefined list, make a phone call or play voice message using only brain waves and optionally blink data. This application has also optional voice feedback

Fig. 2. Values of brain waves retrieved from MindWave Mobile device.

calling a built-in synthesizer for people who have problems with sight or want to establish wireless connection from longer distance (e.g. a few meters) and cannot see the GUI. Such application utilizes real BCI and touchless interface.
Interaction with Brain-Computer Interface in EEG Controller application can be established under the following assumptions:

- connection between MindWave Mobile and mobile device is established,
- user has put the MindWave Mobile properly on the head,
- user can see available options on the screen in a grid or a list.

The switching options can be performed in the following way:

- by single eye blink,
- by double eye blink,
- automatically within given interval (e.g. 1 second, 2 seconds, 3 seconds, etc.),

and under the following assumptions:

- currently chosen option has to be clearly highlighted on the screen,
- optionally, currently chosen option can have voice feedback,
- optionally, voice feedback and method of options switching can be set by the user.

The choosing options can be performed in the following way:

- user has to achieve attention level over a specific value (tested in the end of the time period of the switching option),
- optionally, user has to stay focused for a specific time (e.g. for 1 second, 2 seconds, etc.),

and under the following assumptions:

- optionally the way of choosing options can be configurable,

- optionally user can switch whether he or she wants to use attention or meditation state for choosing options (attention state is recommended for this operation),
- level of attention necessary for choosing specific option by the user can be configurable (user can choose discrete value from 1 to 100).

4. STUDIES

4.1. BRAIN WAVE ANALYSIS

EEG Analyzer collected data of meditation and attention level change in time. As it can be seen both can be very high or very low. Recorded attention level was usually between 40% and 50% during normal functioning of the human brain when the user used a mobile phone. When someone focuses on a specific activity or tries to be concentrated, attention level can increase to 75% or even to 100%. When someone is drowsy or tired, high attention level is very hard or impossible to achieve. Usually tired person will have problems with achieving attention level higher than 50% or 60%. Next, eye blink strength value usually varies between 38% and 60%, but sometimes can be higher and its value can be over 80%. This value can be used as an assistive element for constructing control application.
Basing on the obtained results it can be concluded that it is hard to achieve high meditation or attention level (over 75%) for a longer time (e.g. a few seconds).
High meditation level is harder to achieve and requires from the user to be in relaxed state, which is a problem during the use of a mobile phone. Taking into consideration that fact, attention level seems to be more reasonable value while creating mobile BCI. Next, the value of the blink strength is enclosed in a specific interval with some exceptions. It is more or less constant and it is hard to obtain higher blink strength level in a given second. That is why it is better to use the fact that the user blinked in a specific time than strength of that blink for a prototype control system. The average length of eye blink is from 100 to 400 milliseconds. Application detects, whether person blinked, when two blinks were recorded in interval lower than 800 milliseconds.

4.2. EXPERIMENTS WITH CONTROLLING A MOBILE DEVICE

Conclusions from testing EEG Analyzer were taken into consideration during development of the EEG Controller application. Next, experiments for EEG controller were defined and proper tests were conducted. Examined group of users contained 8 persons in the age range 25-44. Each experiment was performed five times. Each user was sitting still during measurements and was not performing any special activity. Objectives for users were generated randomly from the following list: call the third person from the contact list, play the third message from the list of voice messages, send a predefined SMS or email to the third person from the contact list. The level of difficulty of all objectives was the same. The users had one minute to complete the objective for success.
Results are presented in the table (Tab. 1). Each experiment is described by information about methods of interaction used in the experiment, the percentage of the number of successful attempts, and comment contains additional observations related to the experiment. In 5 out of 10 experiments the objective was achieved (results above 50% are accepted). In the rest, the required function was not activated or an incorrect one was chosen. Results are strongly determined by appropriate configuration of the settings of EEG Controller.

Table 1. Result of experiments.

No.	Methods of interaction	Success	Comment
1	switch: single blink choice: focus 75%	60%	Sometimes incorrect option was chosen. The best time of completed objective was 25 seconds.
2	switch: double blink choice: focus 75%	85%	Proper option was chosen in most of times, but not every time. 19 seconds was the best time in a single experiment.
3	switch: interval - 1s. choice: focus 75%	10%	Proper option cannot be chosen, because option switching interval is too short. Objective is not achieved.
4	switch: interval - 3s. choice: focus 75%	82%	Proper option is chosen in most of times during the tests. The best time is 35 seconds.
5	switch: interval - 5s. choice: focus 75%	16%	It is hard to keep high attention level longer than 3 seconds. This option may work for someone, who is able to keep high attention level longer after training.
6	switch: interval - 3s. choice: focus 5%	0%	Focus level is too low, and highlighted option is chosen every time without specific interaction with the user.
7	switch: interval - 4s. choice: focus 95%	0%	Required focus level is too high. Option of switching interval is too long.
8	switch: interval - 5s. choice: focus 15%	0%	Required focus level is too low. Option of switching interval is too long.
9	switch: interval - 3s. choice: focus 70%	74%	Expected option is chosen. Attention level is appropriate.
10	switch: double blink choice: focus 80%	68%	Expected option is chosen in the most of tests. Objective is achieved.

5. CONCLUSIONS

Summarizing studies, it can be concluded that the best focus level required for choosing an option is about 75%, because it can be achieved by an average person and it is not regular focus level. Higher or lower focus level may cause improper interaction with the user. Another conclusion is the fact, that the best switching option methods are double-blink and automatic switching option with interval equal to 3 seconds. The average person blinks 10 times per minute, so not every single blink can be used as a signal for the mobile application. Double blink is a good method, because it is not a normal human behavior like regular eye blink and can be forced by the user at specific time. EEG Controller has another interesting switching option methods that can be used by persons with paralyzed skeletal muscles. It is the automatic option switching method. Experiment's results shown that the time interval equals 2 seconds or less may be too low in a real situation. The average user may have problems with achieving high attention level in such short period of time. On the other hand time interval equal to 4 or 5 seconds may be too long, because the user may have problems with keeping high attention level for that period of time. An interval equal to 3 seconds seems to be reasonable value for this application as it was proved during the tests. Unfortunately, any pattern or rule representing such situations cannot be distinguished. It simply leads to the conclusion that BCI is not precise. During studies examined persons tried to call proper function several times. In the real it is probably frustrating for the user. There has been recent works on a single-trial classification of EEG data [8]. That approach requires the raw data analysis and will be investigated in the future. The results of experiments show that the best configuration of setting uses attention level and value of interval time in the automatic mode. But first of all, they should be configured separately for each person. In the reality these values depend on different factors: user's health state, user's well-being, atmospheric pressure, time of day, etc. After training with BCI the users achieve better results as well. That carries following conclusion useful for future improvements: application should be individually calibrated every time directly before use.

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