

Control of incoming calls by a Windows Phone based Brain Computer Interface

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Abstract— The research area of “brain control” includes different innovative systems based on brain computer interface (BCI) technology and it is implemented, integrated, studied and tested at universities and research institutes. Using this technology, in this research a complex system has been developed that is suitable to observe EEG signals based on the observation of brain activity, the electric and magnetic signals of neural activity. Furthermore, based on the processing of the measured EEG signals, it is also suitable to implement EEG-based control and testing. Calculating the brain waves of brain activity by using quantitative EEG analysis, the developed test system can control answering and rejecting mobile phone calls. The results of this research can give the basis of helping disabled people or complete limb amputees to establish contacts with others.

I. INTRODUCTION

The brain-computer interface (BCI), also called a mind-machine interface (MMI), a brain-machine interface (BMI), a direct neural interface (DNI) or a synthetic telepathy interface (STI), is a direct communication channel between the brain and an external device. [1] The development of the brain-machine interface started with Hans Berger’s work who recorded brain activity. These were the first human electroencephalograms recorded through the human scalp but the technology at the beginning of the twentieth century was not advanced enough to process and analyze these brain electrical signals. Several developments are in progress in these fields resulting the innovative devices of NeuroSky or Emotive, for instance [2]. The number of research on brain computer interface technology providing the processing and transmission of the measurable signals of the brain has considerably increased in the past twenty years. The devices, which measure, record and process brain signals by signal processing algorithms that define brain signals, have significantly developed as a result of continuous research; for example, smart phone-based applications. While in the early 1990s, only a few publications could be found on the topic of brain-computer interface, currently there are hundreds of studies available. Consequently, the reliability of the technology has remarkably improved. [3]

The brain-computer interface virtually provides an alternate communication channel between a computer application and the user, while at the same time it gives a new hope for users to accomplish data transmission with thoughts. By collecting the information of brain signals generated by the intentions of users, a BCI can convert

these signals into series of sensible instructions or commands. Cognitive neuroscience, multidisciplinary research and developments encouraged researchers to set innovative aims in BCI technology. Its future developments provide new scope of several application opportunities; however, the technology was primarily designed to help people suffering from neuromuscular diseases. Besides the numerous entertainment devices that emerged in the past few years, BCI technology also offers revolutionary new ideas in different research areas, for instance in the development of applications aiming to help disabled patients. [4, 5] This article demonstrates an application possibility in the area of information communication technology, a way how to control a smart phone by a BCI system.

II. BRAIN COMPUTER INTERFACE

The design of BCI systems based on the operation of electroencephalogram (EEG) are relatively simple, mobile, safe and easy to handle. BCI technology gives opportunity to observe brain electrical activity and the processed signals are provided by an EEG device based on the observation of the features of different EEG signal types. The EEG signal measuring and processing devices have extremely developed in the past few years and as a result, new research areas have emerged. When planning and implementing these systems, many criteria should be considered.

A. The aspects of planning and establishing the brain-computer interface of this research

Most BCI systems are based on the non-invasive EEG technology, which is relatively easy to implement. In this method, brain signals are measured by electrodes placed on the scalp. These devices are relatively cheap and as a consequence of constant development, wireless solutions are also available. BCI systems can be categorized into different classes: active, reactive and passive systems, as follows: [6]

- **Active BCI systems:** Independently of external factors, subjects voluntarily generate instructions that are transmitted to an external application. To understand the operation of these BCI systems, the motor operation of the brain, the measured signals recorded during imaginative movement could be mentioned as an example.
- **Reactive BCI systems:** In case of this system, the user is able to control an application in which the reaction of the brain is induced by an external stimulus. These systems can be

modulated directly by users. For instance, P300 and other light stimuli could demonstrate these BCI systems.

- **Passive BCI systems:** The cognitive feedback of arbitrary brain activity of the subject as a result of the outputs of the system without affecting the user. The feedback for excitement or pressure could illustrate these systems for example.

III. THE WINDOWS PHONE-BASED DATA PROCESSING AND CONTROLLING SOFTWARE

In the following, a BCI application that implements the control of answer incoming mobile phone calls will be demonstrated, where the brain-computer interface hardware unit is established with a MindSet EEG headset. The MindSet is a Bluetooth enabled wireless EEG signal measuring device developed by Neurosky. This device can determine the value of attention, in which the basis of implementation is presumably based on previously developed algorithms, for instance in case of patenting the Attention-level analyzer [8]. The developed application is a windows phone-based software, which apart from data procession is also able to control answering and rejecting calls. The control program was written in C# program language, which can analyze and process the transmitted information by the developed direct neural interface hardware.

a. Task specification and requirements

The following requirements should be fulfilled by the software unit:

- it should be able to receive data sent by the EEG headset through serial communication;
- it should be able to check if data transmission error caused by disturbance signal occurs during the transmission phase;
- it should store data in a previously defined, convenient format and structure in case of further procession;
- it should represent the processed data in bar charts to evaluate data;
- it should be able to control answering and rejecting calls according to the measured signals during brain activity with the developed BCI hardware.

To implement the software, Microsoft Visual Studio, one of the most modern developing environments that supports object-oriented programming, was used in Windows operating system. The developing environment supports the well-known, advanced object-oriented C# programming language that best fits to the Windows Phone operating system.

b. Planning

After having chosen the developing environment and realized the requirements, planning was the next phase of developing. Quality greatly determines the efficiency of the project as well as the quality of the final program. Structural alternatives and limits had to be taken into account. From several analyzed solutions, finally the most promising plan was implemented and developed. In the final phase of planning, validation and implementing plans were elaborated.



Figure 1. MindSet EEG headset
(<http://support.neurosky.com/kb/mindset/mindset-diagram>)

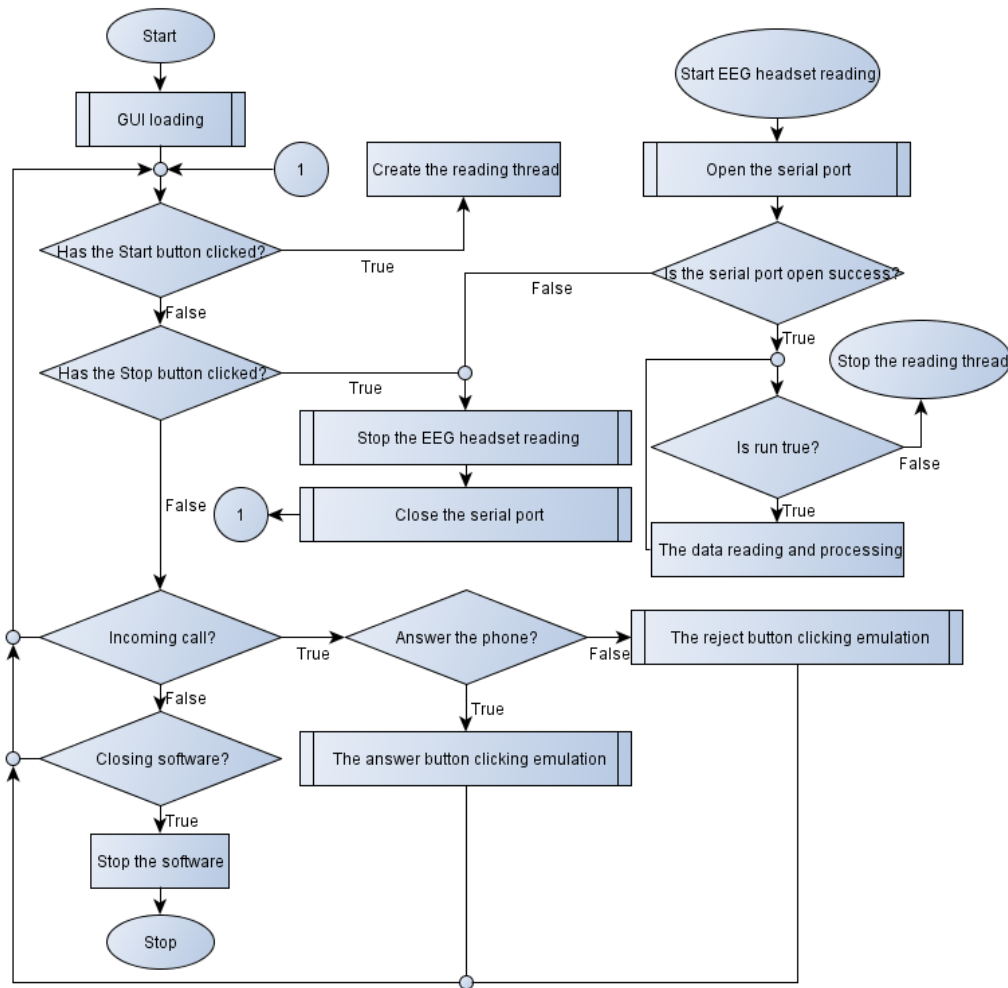


Figure 2. Logic plan of the BCI system in a big way.

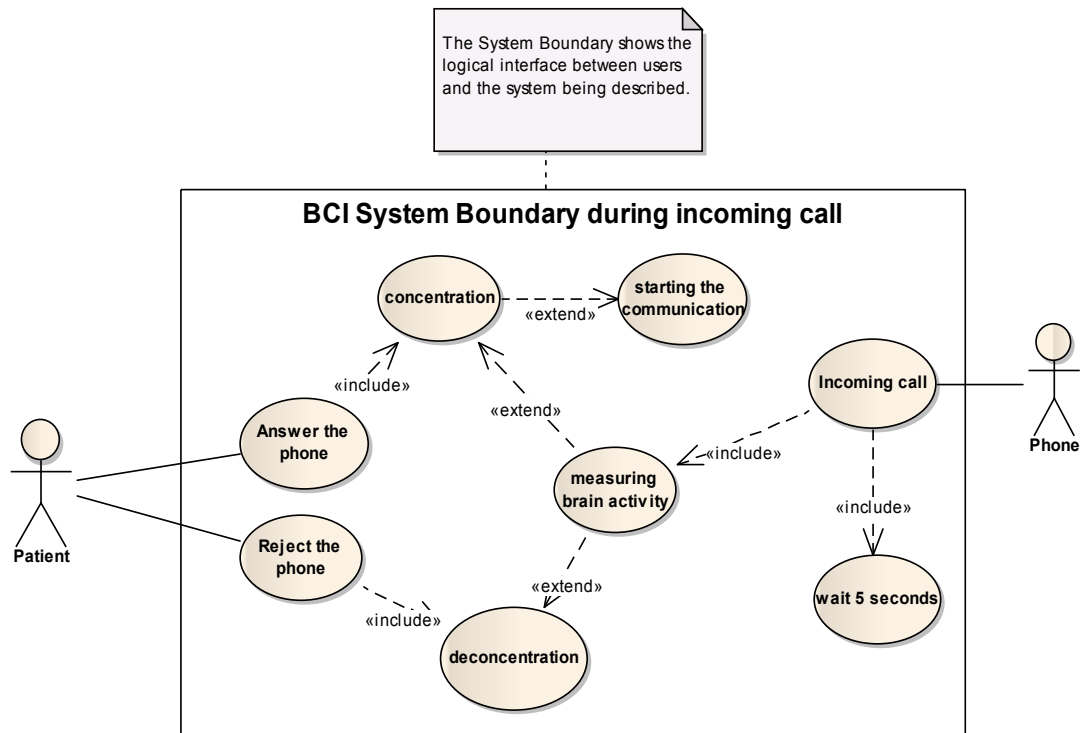


Figure 3. Use case diagram of the BCI system.

c. Implementation and integration

Thorough consideration of data processing and visualizing software and the establishment of designing models preceded the implementation of the program similar to previous development [7]. The application can be divided into three different classes:

- **SerialPortManager:** The serial port is manipulated by the data members and the data functions in accordance with the class identifier;
- **MindFlexReader:** The object of this class is responsible for answering or rejecting incoming calls based on the processed brain waves;
- **OperationForm:** This class in fact consists of two partial classes. The first partial class consists of the code unit managed by the development environment, while the second part is the event manager managed by users. This class is responsible for controlling answering calls.

After the examination of dynamic designing models and requirements, the program can be divided into two main parts functionally: the data processing and visualizing units. The reading, conversion and procession of data coming from the MindSet EEG headset through Bluetooth serial communication are managed by the data processing unit, and signal visualization is accomplished by the visualizing unit in a bar graph. Running the application, the user is offered two options: the application can be started, in which case it runs in the background until it is stopped or the application can be rejected. The program running in the background continuously measures the brain activity. Incoming calls can be answered or rejected by the user without having to press any buttons. Following the incoming call, the software waits 10 seconds to answer or reject the call depending on the attention level.



Figure 4. User Interface (During Incoming call).

d. Verification, Validation

After the implementation and integration, the adequate operation of the established application was tested besides the question whether it met the requirements. The errors and functional disorders of the system were examined during the testing phase, which can be divided into two large phases. The applied models during the developing steps and the adequacy between their specifications were checked. The received results and whether the adequacy between the ready system and the expectations of users are satisfactory according to the functional and other (request for quality, efficiency and resource) requirements claimed in the requirement specification were checked during validation.

The components of the system responsible for answering and rejecting calls were tested separately and independently from one another as well as the services provided by the modules. The joint testing of the modules responsible for calling management is the examination of the system as a whole, including both answering and rejecting calls.

Some implementation errors emerged during the testing phase, all of them have been corrected. Both the black box and the white box methods were used during testing. The latter one helped localizing the above-mentioned coding errors.

IV. TESTS

Regarding the control of answering phone calls, numerous human test subjects and case studies were involved in the use of the data processing and controlling unit established with the developed BCI device.

As it is a human-controlled device, ratings in connection with its usability can only be accomplished by the test subjects and the most important parameters describing the operation of the devices can only be determined with their co-operation. In the case studies, the device was measured and evaluated by an experiment. Both female and male test subjects participated in the testing phase: three men and two women. Two males and one of the females were less than twenty years old and one male and the other female were more than thirty years old. The test subjects were chosen after a voluntary registration.

Control was evaluated in accordance with two main aspects. The first viewpoint was the usability of the established system. Therefore, the test subjects were asked to evaluate it on a scale of 1-5. The other aspect concerned the most important parameter, the operation of the application. In the control of call answering, the most crucial feature of the device was the frequency of errors emerging in answering or rejecting calls.

The control was tested on ten call answering and rejecting with the help of test subject. The opinion about the usability of the device and the results of testing were controversial at the beginning, as the first use of the device was not very successful. According to the evaluation of the test subjects, at first they did not know how to control their thoughts, how to calm their brain activity, in other words, how to reach a calm state of mind or on the contrary, how to focus or concentrate

strongly to start controlling. Consequently, they were not satisfied with the operation of the device, and the measured results were not adequate either. After a short period of practice, the test subjects could use the device more effectively and their opinion changed about its usability, as they succeeded in doing the call controlling tasks. The evaluation of the test subjects in connection with usability and the test results of the experiments could be seen in table 1.

TABLE I.
THE CONTROL OF ANSWERING AND REJECTING PHONE CALLS

Test subjects	Evaluation at the beginning			Evaluation after practice		
	Usability	Errors (answering calls)	Errors (rejecting calls)	Usability	Errors (answering calls)	Errors (rejecting calls)
1.	3	30%	60%	5	10%	30%
2.	3	40%	60%	4	20%	20%
3.	2	10%	90%	3	30%	40%
4.	3	20%	70%	5	20%	20%
5.	2	20%	90%	4	30%	30%
Avg.	2,6	24%	74%	4,2	22%	28%

V. CONCLUSIONS

It becomes clear from the results that the test subjects had difficulties with using the device adequately at the beginning. The control of answering phone calls depends on high concentration / attention value, while rejection assigns to low concentration value. During the first attempts, the major part of answering calls were successful, but call rejection showed high error rates. It is attributable to the fact that active brain activity, such as concentration or attention is easier to reach than the calm state that was assigned to call rejection.

After about half an hour practice, the use of the device improved, as seen in table 1. Regarding the usability of the device, the evaluation of the test subjects improved with more than 1.5 and reached good grade. The control of receiving phone calls, especially rejection, became better after practicing how to reach calm state.

After the experiment, experiences were discussed with the test subjects, as in applying, further developing and modernizing a fully human-controlled device, user experience is of great importance. All test subjects emphasized that they did not know how to control the device adequately with concentration or attention at first, so they could not achieve the desired function well. After some period of study, which does not take some minutes, rather takes tens of minutes, they could control their attention so much that their brain signals became distinguishable by the device, convenient for control. As they acquired this “way of thinking”, the usability of the device proved to be more efficient, the test subjects succeeded more often and started to prefer using the device; moreover, their opinion about the usability of the device became better.

The test subjects found the developed device applicable for achieving the actual aims of the development, i. e. receiving phone calls. Furthermore, all of them found that this technology could spread widely in other applications as well. They mentioned game industry and the devices that could help the disabled in the first place as a possible application area.

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