b-mail: a Brain-Controlled Mail Client[1]

Sofien Gannouni, Nasser Alrayes, Abdulmajeed Alameer Abdulrahman Alsaudi, Ahmad Alabdulkareem
King Saud University
College of Computer and Information Sciences
Department of Computer Science
Saudi Arabia

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ABSTRACT: *For centuries, humans fantasized about the idea of controlling objects only by thoughts. In the last decade, this idea has shifted from fantasy or science fiction to reality. Brain Computer Interfaces (BCI) have made this a reality. A BCI is a communication channel between the brain and a computer program or application. It allows the development of new applications that provide assistance to people with disabilities in regular everyday activities, making them accessible and easy to perform. We present in this paper a simple yet efficient email client which enables severely motor-disabled people to open, compose, send, reply and forward emails. It performs a real-time classification of user's brain activity signals using the P300 technique and performs the appropriate corresponding actions.*

Categories and Subject Descriptors
H.1.2 [User/Machine Systems]: Human factors; **H.5.2 [User Interfaces]:** Interaction styles; **H.4.3 [Communications Applications];** Electronic mail

General Terms: Human-computer interaction, User Interface, Email

Keywords: Assistive technology, Brain computer interface, People with disabilities, P300-Technique, Mail client

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1. Introduction

The ubiquity of processor-based machines and the increasing growth of computing techniques have changed the way we deal with everyday devices, such as TV, HIFI, telephone, etc. Controlling these devices has evolved from direct control to remote control, and recently to brain control. In the last decade, the Brain Computer Interface (BCI) has emerged as a new type of human computer interfaces [1, 2, 3]. A BCI aims to help people, suffering from severe disabilities, to restore communication with their environment through an alternative interface [4]. It represents a communication channel between the human brain and a machine without any movement simply by thinking. This mental activity leads to changes of electrophysiological signals like the Electroencephalogram (EEG) or Electrocorticogram (ECoG). A BCI system is responsible for acquiring, measuring such changes and translating them into control commands.

E-mail is one of the most important and common communication media in our world nowadays. Almost everyone is using e-mails on a daily basis. However, there are many people who lack the ability to use this essential communication medium. Such people include those with diseases that could impair the neuromuscular channels such as amyotrophic lateral sclerosis (ALS), spinal cord injury and cerebral palsy. People with those disabilities deserve to have an alternative method which will give them the ability to communicate. We present in this paper a mail-client application which allows motor disabled people to access their email accounts in a productive way. The proposed system translates the brain activity signals into control commands using the BCI2000 framework [5, 6]. The BCI2000 offers basics for brain signals acquisition, filtering and processing. Our system defines the control commands that are generated when P300 responses (changes of brain signals) occur. It is responsible for mapping these generated commands into actions that deal with the client's email account.

2. Related work

In the literature review there are mainly three different techniques adopted by BCI systems:

- The Event-Related Desynchronization/Synchronization (ERD/ERS): is the decrease/increase in synchronous activity when responding to an event [6]. It is a signal that is measured when a person imagines a motor movement. These signals are captured from the Somatomotor Cortex (see figure 1). The BCI system translates the user's motor-imaginations signals into actions. Some applications have been developed using this technique [8, 9, 10]. All of them are characterized by a low degree of accuracy and require a long time (hours) of training.
- The P300 is one of the Event Related Potential (ERP) responses which can be measured after 300 milliseconds [11]. When a visual stimulus occurs, a response appears as a positive deflection in voltage. Figure 2 represents the corresponding signal after 300 ms. In order to detect the response, the electrodes should cover the Parietal lobe of the brain (see figure 1). Many prototypes have adopted this technique [12, 13, 14, 15]. All of them are characterized by a high degree of accuracy and require a short time (minutes) of training.
- Steady-State Visual Evoked Potential (SSVEP) is an oscillatory wave responding to visual stimulus in a repetitive way at a specific frequency (harmonic) [16]. The main principle of

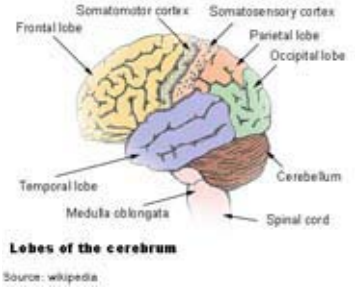

Figure 1. Brain Lobes

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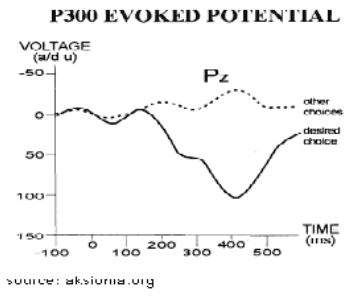


Figure 2. P300 response

SSVEP is that the EEG signals recorded from the occipital lobe region (see figure 1) of a user who is focusing on a light that is flickering with some frequency, will match the same frequency. Some applications have been developed using this technique [17, 18, 19, 20, 21]. Most of them are characterized by a very high degree of accuracy and require a very short time (few minutes) of training.

In this paper, we briefly describe the most widely known applications that have been developed using the P300 technique. These applications include:

The P300 Speller: It was the first system that used the P300 signal as a controller in a BCI [12]. The user has to focus his attention on characters displayed in a 6x6 matrix flashing randomly. The system locates the desired character and generates a voice pronunciation of that character.

The P300 2-D cursor: It is a 2-Dimensional cursor control system and consists of flashing randomly 4 arrows on the screen indication 4 possible directions: upward, downward, rightward and leftward. When a P300 response is detected, the cursor moves to the desired direction [13].

Simple Questions System: The system provides the user with four choices: “Yes”, “No”, “pass” and “end” which are flashing randomly. The system asks the users a set of simple questions which can be answered by “YES” or “NO” and the user just has to pay attention to the correct answer [14].

Virtual Home System: It provides six different images as stimulus for the user. The images are a television, telephone, lamp, door, window and a radio. The user has to count in his mind how many times the desired image flashed and the system detects the response [15].

3. Overview of *b-mail*

3.1 System Description

The system has defined two sets of commands. The first one represents the menu of *b-mail* (see figure 3). The second one specifies a virtual keyboard (see figure 4) which allows the user writing destination email-addresses and messages. These commands are displayed as P300 matrices (see figures 3 and 4).

The rows and the columns in the menu or virtual-keyboard matrix flash randomly. When the flashing row or column contains the desired command or letter, a P300 response is triggered in the subject’s brain activity. The P300 is a response to a visual stimulus that can be measured after 300 milliseconds. Our system identifies which row or column was flashing and what was the desired command or letter and performs the corresponding action.

Using the command matrices, the users of *b-mail* have access to their mail accounts. *B-mail* allows them browsing, opening,

Figure 3. *b-mail* menu matrix

Figure 4. virtual-keyboard matrix

replying, forwarding, composing and sending emails. It retrieves the user’s emails from his email-account, displays them on the screen and stores them in a local *SQLite* [22] mail database (see figure 5). Incremental updates of the local *SQLite* mail database are made periodically.

3.2 System Architecture

The system is divided into two parts. The first part is the BCI2000 module which is implemented using C++ programming language. And the second one is the e-mail client module which works on top of the java virtual machine. The two parts are connected using UDP communication channel. As depicted in figure 6, *b-mail* is composed of many modules. We list the most important ones below:

- **Signal Acquisition:** The purpose of the *Signal Acquisition* module is to translate the brain activity measures using EEG into digitized signals.

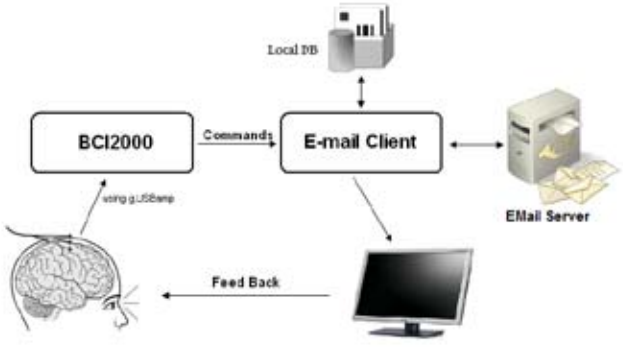


Figure 5. *b-mail*

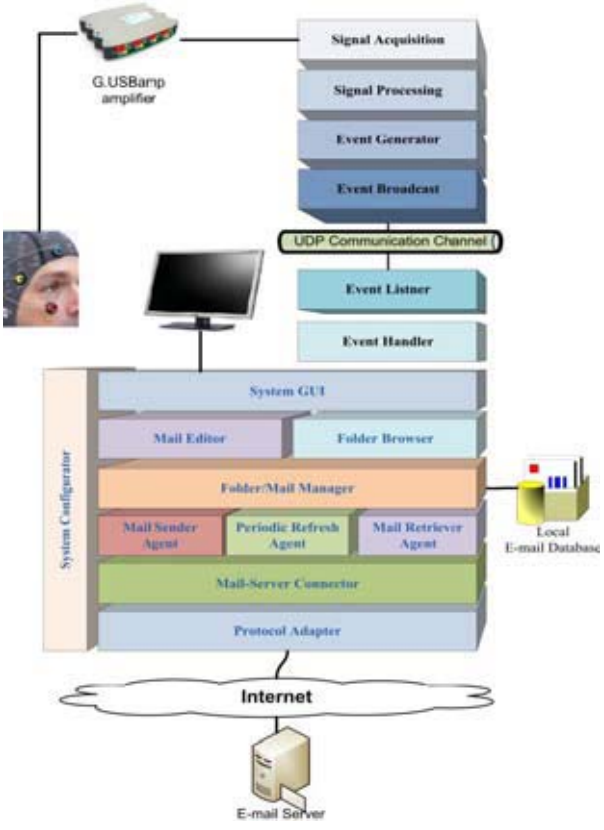


Figure 6. System Architecture

- **Signal Processing:** The *Signal Processing* module is responsible for applying the classification process to select the features from the filtered signals (i.e. the positive amplitude in the filtered signal) using a linear classifier.
- **Event Generator:** The *Event Generator* module gets the results of the classification process from the Signal Processing module, and generates an event that is sent using the Event Broadcast module.
- **Event Broadcast:** *The Event Broadcast* module opens a UDP Socket on a predefined port and sends the events through it.
- **Event Listener:** The *Event Listener* module listens to the predefined UDP port in order to receive the events sent by the *Event Broadcast* module. The received command is delivered to the Event Handler module.
- **Event Handler:** The *Event Handler* translates the event to a command and then performs the corresponding action. The commands are handled in a generic way, which allows augmenting the system's capabilities and increasing its vertical scalability. Using the Java reflection mechanism, the *Event Handler* recognizes and dynamically invokes the action that should be performed when a command is detected.
- **Folder Browser**: It performs basic operations that are common to the different folders in the mail server such as, Inbox, Sent, Spam, etc.
- **Periodic Refresh Agent:** The *Periodic Refresh Agent* is connected to the server using the Mail Server Connector module. It checks for new messages in the server every specific period of time. If any new messages are received, they are sent to the *Folder/Mail Manger* module to be saved into the database and to be displayed on the screen.
- **Mail Server Connector:** It is responsible for establishing the connection with mail server and for providing uniform access to the services of the remote mail sever.
- **Protocol Adapter:** *Protocol Adapter* allows the system to support different communication protocols that could be adopted by mail servers. The protocol can be either Post Office Protocol version 3 (POP3) or Internet Message Access Protocol (IMAP).
- **System Configuration:** System Configuration Module is responsible for specifying the required settings to establish the connection with the mail server. These settings include the addresses, ports of the Incoming and outgoing mail servers, user account login and password.

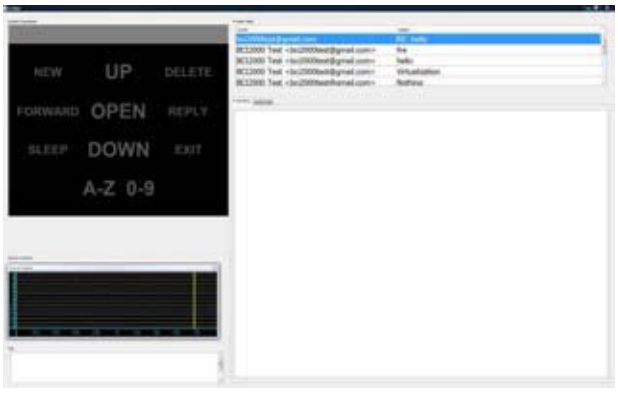
4. Prototyping

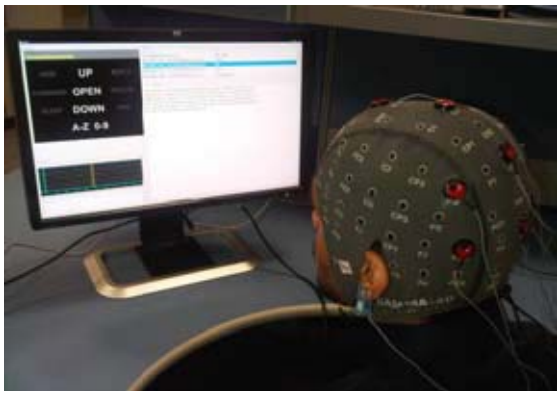
The system is fully developed using Java programming language and interacts with external components such as DBMSs and email-servers using standard middleware including Javamail, JDBC, etc. These middleware increase the ability of the system to adopt new technologies. Moreover, the system supports several internet standard protocols such as SMTP, POP3 and IMAP.

5. Results and Discussion

B-mail has been tested by normal people. The accuracy of the system to recognize the submitted commands is about 97 per cent. However, there are many factors that may reduce this rate. These factors include:

- *Luminosity*: b-mail detects P300 responses triggered in the subject's brain activity in response to visual stimuli. The efficiency of the visual stimuli decreases by up to 7% when users are placed in a brightly lit environment. In order to solve this issue, we are implementing a new feature in b-mail allowing the user to increase or decrease the light intensity of his screen. We are also studying multiple flashing approaches that may preserve the accuracy of the system in a brightly lit environment.
- *Screen size*: We have tested b-mail using different screen sizes: 14 inches, 17 inches and 24 inches. The accuracy of





the system is very high with 17 and 24 inches screens. It goes down by up to 9% with 14 inches screens. This is due to the shrinking of the size of visual stimuli and their density on the screen. In order to solve this problem we are studying the ability to auto-accommodate (meaning to auto-reduce the size of) the *b-mail menu* and *virtual-keyboard* P300 matrices dimensions with the screen size.

- *User fatigue*: Working with b-mail requires a high degree of concentration by the user. This concentration decreases proportionally with the amount spent by the user on the system. This may lead to a reduction by up to 11% in the accuracy of the system. To overcome with this inconvenient, we are studying the accuracy of the system at different stages (beginning, after 30 minutes, after one hour, etc.) of the user session using different inter-stimulus intervals. This study may help us to identify the optimal inter-stimulus interval appropriate to every stage of a user session. The system should be customized according to the results of this study.

Users of b-mail may tape up to 8 characters per minute. In order to enhance the system input rate, we are studying many features. We are suggesting that an auto-complete module be added to the system in order to reduce the number of entered characters when composing, replying or forwarding messages. We intend also, to develop a set of template messages that may be used to send messages with minimum effort.

6. Conclusion and Perspectives

We have proposed and successfully implemented a brain-controlled mail client that enables severely motor-disabled people to browse, open, compose, send, reply and forward emails. The system is composed mainly of two parts. The first part acquires the user's brain activity signals in response to visual stimuli, analysis them and translates them to commands. The visual stimuli are rows and columns of a P300 matrix that are flashing randomly and that represent the system commands. We have used the P300 technique in order to map the signals to commands. The second part of the system is mainly responsible of performing the actions that are appropriate to the identified commands. The mapping of commands to actions is implemented in a generic way allowing as such dynamic method invocation.

The accuracy of the system is nearly 100%. However its responsiveness still requires some enhancements. We intend to re-implement the analysis of brain activity signals in a parallel way. The parallel processing of the signals analysis would speed-up the system. We intend also to provide a set of predefined template messages that allow the user to compose new messages with minimal efforts.

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