35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

A Brain-computer Interface controlled Mail Client

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Abstract— **In this paper, we propose a brain-computer interface (BCI) based mail client. This system is controlled by hybrid features extracted from scalp-recorded electroencephalographic (EEG). We emulate the computer mouse by the motor imagery-based mu rhythm and the P300 potential. Furthermore, an adaptive P300 speller is included to provide text input function. With this BCI mail client, users can receive, read, write mails, as well as attach files in mail writing. The system has been tested on 3 subjects. Experimental results show that mail communication with this system is feasible.**

Keywords: Brain-computer interface, Electroencephalography, Mouse control, P300 speller, Mail client.

I. INTRODUCTION

Brain-computer interfaces (BCIs) directly translate brain activities recorded on the scalp into control commands by bypassing the normal neuromuscular pathways, thus enable users with motor disabilities to convey their thoughts and intentions to the external world [1], [2], [3]. Significant progress in this field has been achieved to enhance the quality of life for paralyzed people in recent decades. A large amount of real-world applications of BCIs have been developed to accommodate different requirements, such as word spelling [4], [5], environment control [6], neural prothesis control [7], wheelchair control [8], [9] and gaming [10].

Electronic mail, as a medium for rich communication, is a preferred communication tool in our daily life. But to our knowledge, there is not yet a BCI based mail client in the literatures. It is mainly due to the fact that the use of a mail client is usually based on a computer mouse, which should be capable to do arbitrary point to point movement and clicking, while implementation of such a BCI based mouse is a tricky problem. In our previous studies [11], [12], we presented a hybrid BCI incorporating motor imagery-based ERD/ERS and the P300 potential for continuous 2-D cursor movement control and target selection/clicking. This hybrid approach was successfully applied to a BCI browser for Internet surfing [13].

In this paper, we propose a BCI mail client as a novel application of hybrid BCI. The control of this mail client is based on a BCI mouse, which consists of two-dimensional cursor movement and target selection. Specifically, users control the vertical and horizontal movement of the mouse by the detection of P300 and motor imagery respectively, while they use P300 and motor imagery collaboratively to decide the selection or rejection of a target (menus, buttons and text input boxes). Furthermore, An adaptive P300 speller is employed to input mail content. With this mail client, users have access to receiving, reading, writing, replying and forwarding of emails, as well as file attaching.

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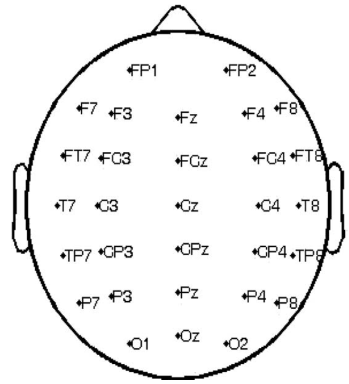

Fig. 1. Names and distribution of electrodes.

II. METHODOLOGY

In this section, the system paradigm is first described. Next, the mouse movement control and target selection are summarized. Finally, the adaptive detection of P300 potential for text input is described in detail.

A. System paradigm

Scalp EEG signals were recorded with a SynAmps2 amplifier using 32 channels Quik-Cap^{TM} (Neuroscan Compumedics)) at a sampling rate of 250Hz and band-pass filtered between 0.05 and 40 Hz. Two channels "HEOG" and "VEOG" representing eye movements were excluded for signal processing. The remaining 30 channels were used without further channel selection, which are shown in Fig. 1 [11].

The graphical user interface (GUI) is presented in Fig. 2. There are eight buttons around the client area of the graphical user interface (GUI) with 3 buttons labeled "UP" at the top, 3 buttons labeled "DOWN" at the bottom, and two buttons labeled "STOP" in the middle. During mouse control, these buttons flash in a random order to elicit P300 potentials when users focus attention on one of them. And the mail client is embedded in the center client area.

The user controls the vertical movement of the mouse by paying attention to a specified "UP"/"DOWN" button. That

Fig. 2. GUI of the BCI mail client in which mail client is embedded in the center client area, and eight flashing buttons ("UP", "DOWN" and "STOP") are placed around it.

is, he/she moves the mouse up/down by attending to one of the three "UP"/"DOWN" buttons. If no vertical movement is needed, the user can focus on one of the two "STOP" buttons. Meanwhile, the horizontal movement of the mouse is controlled by the user's motor imagery. Specifically, the user moves the mouse toward right by imaging moving his right hand, and vice versa [11]. For target selection or rejection, the motor imagery and P300 features work collaboratively as follows. If the target is an intended one, the user can make a selection by paying attention to the "STOP" button on the left side and stopping motor imagery for a while (i.e., in a so-called idle state of motor imagery). Otherwise, if the target is of no interest, he/she can reject it by continuing motor imagery without paying attention to the "STOP" button (i.e., in a so-called idle state of P300) [12].

In the mail client GUI, each of the selectable targets is indicated by a translucent target box, which is placed on top the target and is visible only when the mouse reaches it (see Fig. 2). Basic mail communication functions, such as receiving, reading, creating, replying and forwarding mails, as well as attaching files are included in this mail client. We describe the following mail functions of this mail client here.

1) **Receiving:** Users move the mouse to select the "Receive" button to receive new incoming mails).
2) **Reading, Replying, Forwarding:** Mails are listed in the "Inbox" with the titles linked to the mail contents (see Fig. 2). By moving the mouse to activate a link, users open the corresponding mail content and read it. Users select the "Reply"/"Forward" button to reply/forward the reading mail.
3) **Creating:** Users move the mouse to select the "New" button to initiate a piece of mail.
4) **Writing:** After creating/replying/forwarding a piece of mail, users enter a mail writing interface. They fill or change the "To" address, the mail subject and the content here, and send this mail once it's completed by selecting the "Send" button.
5) **Attaching files:** In the mail writing step, users can select the "Add Attachment" link to open a file explorer interface. Users traverse the local file system to select files to be attached.

B. Mouse movement control

The vertical movement and the horizontal movement of the mouse are controlled by P300 and motor imagery respectively. We briefly describe this method here, and the details can be found in [11].

The position of the mouse is updated every 200 ms in our system. For the vertical movement control of the mouse, the velocity is fixed and the direction $c(k)$ of the kth update is determined by P300 detection. That is, if P300 potential is detected at one of the three "UP" buttons, $c(k)$ is set to 1 and the mouse moves upward; If P300 potential is detected at one of the three "DOWN" buttons, $c(k)$ is set to -1, and the mouse moves down; If P300 potential is detected at one of the two "STOP" buttons, $c(k)$ is set to 0, and the mouse has no vertical movement; If no P300 potential is detected at any button, $c(k)$ keeps its value, and the direction of vertical movement of the mouse does not change. For details of the P300 detection algorithm, readers can refer to [11]. The vertical coordinate of the mouse is updated according to

$$y(k) = y(k-1) + c(k)v_0, c(k) \in \{-1, 0, 1\}, \qquad (1)$$

where v_0 is a speed constant which was set to 10 pixels in our experiments and can be further tuned according the the users' performance.

For the horizontal movement control, the position of the mouse in the kth update is determined by the classification result of mu/beta rhythm of left and right hand motor imagery. Given the SVM classification score $f(k)$, the horizontal coordinate of the mouse is updated according to

$$x(k) = x(k-1) + a_x[f(k-2) + f(k-1) + f(k)] + b_x, \qquad (2)$$

where the parameters a_x and b_x are calibrated just before an online experiment such that the absolute value of the difference $(x(k) - x(k-1))$ is close to zero when the subject is in a idle state of motor imagery (see [11]).

Users can move the mouse from an arbitrary initial position to an arbitrary target position with the above control method based on both P300 potential and $mu/beta$ rhythm.

C. Target selection or rejection

A hybrid approach which combines both P300 potential and mu rhythm for target selection, as in in [12], is employed in our system. Specifically, if an interested target is reached by the mouse, the user can select it by focusing on the left flashing button "STOP" in the mail client GUI and making no any motor imagery. Otherwise, the user can reject it by continuing motor imagery and paying no attention to the "STOP" button. In other words, one state with a P300 potential detected at the left "STOP" button and no motor imagery implies a selection of the currently reached target, and the other state with left/right motor imagery and no P300 potential detected at the left "STOP" buttons means a rejection. Given an epoch of EEG signals, we extract both P300 feature and mu rhythm feature, then concatenate them to construct a hybrid feature vector which is classified by a trained SVM classifier. If the predicted label of this feature

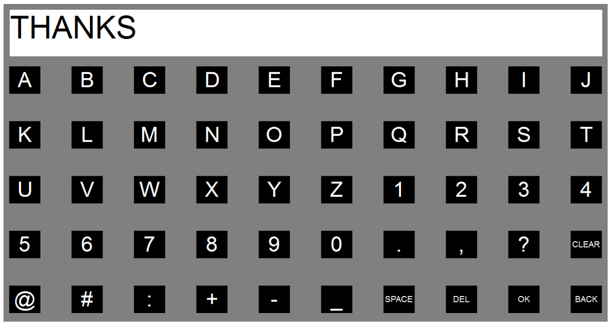

Fig. 3. GUI of the P300 based speller which is used for target filtering. Fifty buttons arranged in a 5 by 10 stimuli matrix correspond to 45 characters and 5 functional keys. Functional key "CLEAR": clearing all the input characters, "SPACE": inputting a space, "DEL": deleting the last input character, "OK": return to the mail client interface with the input text, and "BACK": canceling the input text and returning to the mail client interface.

vector is 1, then the target is selected; Otherwise, the target is rejected.

D. Adaptive P300 word spelling

To facilitate text input for mail writing, an adaptive P300 speller is integrated into the mail client (see Fig. 3).

This P300 speller adaptively selects the number of epochs to average, according to the subject's current performance. Specifically, for all 30 channels, the most recent 0-600 ms segment after each character flashes are 0.1-20Hz bandpass filtered, 1/6 down-sampled, and then concatenated to construct a feature vector. A P300 stimulus round consists of 50 flashes, one for each character, thus 50 feature vectors. Give a new round, $l+1$ (l is initialized to 0) rounds of feature vectors are classified by a Bayesian Linear Discriminant Analysis (BLDA) classifier [14] trained previously to obtain the same rounds of classification scores. These scores are average by character to result in 50 scores, which are then normalized to between 0 and 1. The final output $c(k)$ of the kth round is determined by the difference of the maximum and the second maximum score $\Delta\theta$ given a threshold θ_0 and two parameters that limits the minimum (l_{min}) and maximum (l_{max}) number of rounds to average respectively. In other words, when at least l_{min} rounds of data is collected and if $\Delta\theta$ exceeds the threshold θ_0 or l reaches l_{max}, the system outputs the character corresponding to the maximum score and l is reset to 0. Otherwise, the system continues to collect another round of data to determine the output. And note that l_{min} and l_{max} is set to 3 and 8 respectively, and θ_0 is set to between 0.2 and 0.3 according to the users' performance.

III. Experiments and results

Three subjects from the local research unit, aged from 23 to 30, attended the online experiments. Before the online experiment, two data sets were collected, which took about half an hour, from each subject to set parameters of three models as below. Dataset I: Each subject attended a P300 calibration session of 20 trials with the GUI of the P300 speller (see Fig. 3). Specifically, in each trial, all 50 buttons flashed in a random order and each button flashed 10 times. Simultaneously, the subject was instructed to focus his attention on a given button. Dataset II: In this calibration session, there were 3 classes of trials performed by each subject. Each class contained 30 trials and each trial lasted 4s. In each trial, a cue (left/right/upward arrow) appeared to instruct a task, while the 8 buttons flashed in a random order (the buttons' positions can be referred to Fig. 2). The P300 stimuli were synchronized with cue's appearance, i.e., the stimuli began once an arrow appeared and ended when it disappeared. When a left arrow/right arrow appeared, the subject imagined left/right hand motor without paying attention to any flashing button. On the other hand, the subject focused on the "STOP" button without any motor imagery when an upward arrow appeared. P300 model: Dataset I was used to construct a P300 classification model for text input as well as control of mouse's vertical movement. Motor imagery model: The left/right motor imagery trials in Dataset II were used to setup model for motor imagery detection. Hybrid model: all trials in Dataset II were divided into trials of selection (trials with up arrow cue) and rejection (trials with left/right arrow) and were further employed to calibrate model for target selection.

A. Online experiment

In the online experiment, all the three subjects were requested to complete a task of receiving mails and replying to the latest mail with attachment. This task for each subject contained the following 9 operations:

1) Activate the mail client from the predefined home page using the BCI mouse.
2) After the mail client was opened, the subject would move the mouse toward the "Receive" button and select it.
3) Once the receiving procedure finished, the mail client returned to the "Inbox". The subject would move the mouse and open latest piece of mail.
4) The subject would reply the writer by moving the mouse to select the "Reply" button after reading the mail.
5) The subject would select "Add attachment" button by the mouse to attach a file to this response.
6) In the file list view, the subject select the last file as an attachment.
7) The subject would select the text input.
8) The system was switched to a P300 speller interface (see Fig. 3). The subject would input mail content, e.g., a simple sentence.
9) After text input with the P300 speller, the GUI returned to the "Reply" step. The subject should move the mouse and select the "Send" button to send the response.

Once the above nine steps were completed, the mail client returned to the main menu for the next trial. The whole procedure is illustrated in Fig. 4. Each of the subjects repeated this task for 5 times (trials).

In this experiment, the subjects performed at least eight selections using the BCI mouse to finish a complete trial.

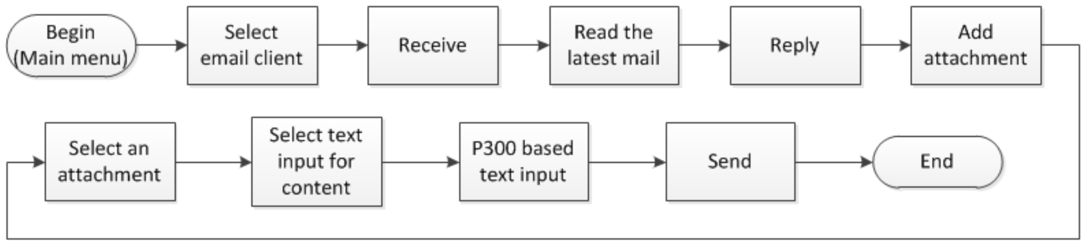

Fig. 4. The online experiment flow which includes 9 operations.

TABLE I
RESULTS OF ONLINE EXPERIMENT. EACH TRIAL OF THIS EXPERIMENT INCLUDES 9 OPERATIONS AS SHOWN IN FIG. 4. "NO. SELECTIONS": THE AVERAGE NUMBER OF SELECTIONS PERFORMED IN A TRIAL; "NO. CHARACTERS": THE AVERAGE NUMBER OF ACTUAL INPUT CHARACTERS FOR TEXT INPUT; "SPELLING TIME": THE AVERAGE TIME FOR TEXT INPUT; "TRIAL TIME": THE AVERAGE TIME OF A COMPLETE TRIAL.

Subject	No. trials	No. selections	No. characters	Spelling time (s)	Trial time (s)
S1	5	8.0	8.2	101.33	414.62
S2	5	8.8	7.2	99.68	444.14
S3	5	8.25	8.0	96.88	422.10

If an unintended target was selected, the subject needed to select the "Back" button or the menus in the main menu bar to return to the previous step. This implied that more than eight selections might be needed. During text input, the subject could select the function key "DEL" or "CLEAR" to delete typos. Table I shows the results of the online experiment, including the number of trials for each subject, the average number of selection operations, the average number of input characters for target filtering, the average time of text spelling and the average time of a complete trial.

In the online experiment, tasks with multiple mouse operations and text input, were much more complicated. These comprehensive task assessed most of the important functions that were available through the BCI mail client. Most of the subjects could finish one task within 7 minutes and 30 seconds with few mistaken selections. It took a relative long time to complete a trial in this experiment which might arise from the extra selection operations for selecting the target filtering edit box as well as the time consuming text input. Also, switch of work modes (mouse operation mode and text spelling mode) and the varied speed of internet connection, which affects the receiving operation, will bring extra time cost. All users, however, were able to complete such a complex task within an acceptable interval.

IV. CONCLUSIONS

This study presents a hybrid BCI-based mail client, as a real world application of BCIs. Common functions of a mail client including receiving, reading, writing mails, and attaching files are implemented in this system. This mail client is based on a hybrid BCI mouse. The BCI mouse control including the 2-D movement control and target selection is implemented using the P300 potential and motor imagery-related mu rhythm. Using the BCI mouse to select function keys, the user can operate the mail client. Furthermore, an adaptive P300 speller is incorporated for text input. Experimental results show that users have access to basic mail communication through this BCI mail client.

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