Touchless Virtual Keyboard Controlled by Eye Blinking and EEG Signals

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Touchless virtual keyboard controlled by eye blinking and EEG signals - *DRAFT VERSION*

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Abstract. The paper describes the idea of touchless virtual keyboard designed for disabled people with tetraparesis. Each key can be selected by three double eye blinks registered by EMG sensor. EEG signals are used as a support that allows the user to change the input mode of single characters to the mode of predicted words selection. The keyboard was implemented and evaluated during provided experiments. Obtained result ($WPM = 1.11$) partially confirms the calculated typing speed ($WPM = 1.23$). It is also found that the keyboard efficiency can be improved by using a list of predicted words, even the number of those words is low and they are short ($WPM = 1.27$). Provided discuss presents that improved keyboard used by experienced users could achieve the typing efficiency even up to $WPM = 3.15$.

Keywords: virtual keyboard, text entry, brain-computer interface, BCI, eye blinking

1 Introduction

Communication and the ability to interact with the environment, especially to other people, are fundamental needs for human relationships. For people who suffer from severe physical disabilities, because they are completely paralyzed, ability to comply with this need is almost impossible. Their physical activities very often are limited to eye blinking. Although it is sufficient to communicate using Morse code - this method is very cumbersome. Human-Computer Interaction (HCI) researchers explore opportunities of using as many sensors channels as possible [24]. Among others, in support to impaired physical activity, bioelectrical brain signals can be used to provide an alternative communication channel. A Brain-Computer Interface (BCI) is able to recognize changes in the ongoing bioelectrical signals and to use them to appropriate commands in order to realize the communication aids.

The aim of the project was to propose useful BCI, which allow users with severe motor disabilities to use virtual keyboard. The electroencephalographic (EEG) devices mostly measure fundamental human activity states as attention and relaxation (meditation). The devices sometimes integrates also an electromyographic sensor that can be used for eye blinks recognition. Such signals can be sufficient to type characters on a virtual keyboard. The problem is to design the appropriate method to move among virtual keys and select the characters in order to achieve the efficient text entry.

2 Related Works

Eye blinking is a semi-autonomic rapid closing of the eyelid. Although it is the essential function of the eye that helps spread tears across and remove irritants from its surface, it can also play important role in the human-computer interaction. Most of researches use eye blinks as an additional element in eye-tracking systems [4]. Sometimes eye blink detection as a valuable supplement for faster mouse click emulation [7]. There are also several ways to write by gaze [12]. In a typical setup, gaze direction is used to point and select letters on an on-screen keyboard. Average efficiency of such solutions is about 5 WPM (*Words Per Minute*). Alternatively, if the person cannot fixate and use traditional eye-tracking system, the eyes can be used as switches using blinks to enter and correct text [20]. Each kind of text entry, even using a single input as blinks, can be improved (increase of the text entry speed) implementing words prediction [21]. Most of the methods used to detect blinking are based on image processing [17, 8].

In the recent years, a noticeable 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 published [5]. A lot of implemented BCI applications are associated with different areas, i.e.: mental speller [2] mouse control [14], robot arm control [3], game applications [13], navigation [23], drowsiness detection system [9], brain-controlled smart home system [10], cognitive ability assessment system [18], etc.. EEG applied to control a virtual keyboard gave results from 0.85 [16] up to $CPM = 3.38$ (*Characters Per Minute*) in error-free writing [19]. Some researchers noticed that the EEG and EMG data can be used at the same time in order to improve the accuracy of user input when using the biometric signal to the computer interface [6].

The aim of this work was to propose a new method of typing using eye blinking with a support of EEG signals and words prediction.

3 Research Environment

3.1 EEG Device

The main element of the research environment is the EEG device. One of commonly available consumer of EEG signals is the NeuroSky MindWave Mobile [15]. Devices developed by this producer are inexpensive, work well using a dry electrode and have their own Software Development Kit, so software developers can easily create own applications. The NeuroSky Mindwave Mobile has also good measurement accuracy, which can result in a wider group of potential users.

The device is composed of one dry electrode and a specially designed electronic circuit. It covers of a headset, an ear-clip, and a sensor arm. 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 spectrum (alpha waves, beta waves, etc.). The sensor arm includes also EMG sensor that allows the user to measure the blink strength. The headset transfers data via Bluetooth.

Typically, real time EEG signal processing and classification algorithms are designed for powerful machines. Some of them use a weighted combination of various classifiers. However, the producer's firmware reduces the complexity of managing the connection and handles parsing of the data stream from the EEG headset. This comfortable software interface supplies both raw data and preprocessed data. The software developer receives the value of attention and meditation 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.

3.2 Software Tool

Developed research tool (`https://platforma.polsl.pl/rau2/file.php/675/NeuroKeyboard.zip`) has a form of a desktop application. The computer requires a Bluetooth connection to communicate with the EEG device. First, the EEG device must be paired to the computer, and then the virtual keyboard application can be started. Next, the user gets a graphical interface consisting of four parts responsible for different elements of functionality (Fig.1).

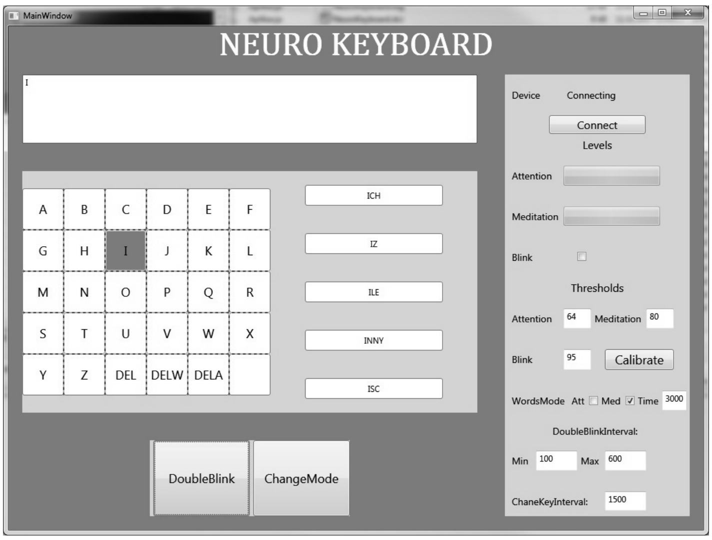

Fig. 1. Graphical user interface of the research tool.

They are:

- text area presenting the typed text - selected characters are automatically added at the end of the text,
- virtual keyboard containing five rows of keys and the list of predicted words,
- configuration panel - informs about the state of connection to the MindWave device, covers following information: current values of attention, meditation and blinks, configuration settings, and *Calibrate* button that is used to personalize the thresholds,
- simulation panel - covers two screen buttons: *DoubleBlink* and *ChangeMode*.

The virtual keyboard allows the user to personalize operating parameters. Settings are: meditation threshold, attention threshold, time above the thresholds, eye blinking strength, time period for eye double-blink, interval of switching between the keyboard sections.

4 Method

The virtual keyboard can work in two modes: character selection, predicted word selection. Expecting that all operations controlled by EEG signals will be realized very slowly, we decided that the switch between the keyboard sections will be executed automatically at specified intervals. Assuming the switch between single keys takes place every second, then enter a ten-letter word would take 3-5 minutes, which is unsatisfactory result. In order to accelerate the selection of the correct character, the *Divide and Conquer* algorithm was implemented. Therefore, first a row of characters is selected. Highlighted row of keys changes to the next one at a certain time until the selection. The change of rows proceeds automatically from top to bottom (Fig.2). Then the first row is highlighted again.

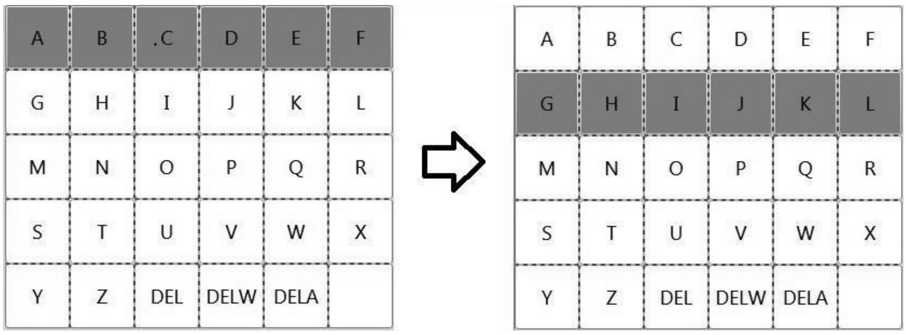

Fig. 2. Selection of the key - step 1.

After the row selection, the line of six characters is divided into two parts, which are alternately highlighted. After the part selection, current group of three characters are divided into single keys (Fig.3). They are also alternately highlighted in certain time period. Finally, after the key selection, the corresponding character is inserted at the end of the text area.

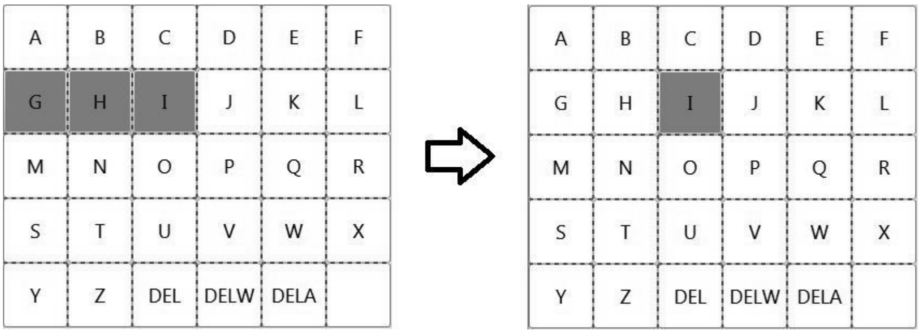

Fig. 3. Selection of the key - step 2.

The most common operation is the selection, so we decided to use an eye double blink for that. Double blink is chosen to filter out the involuntary blinking. The user must use double blink three times to select required key.

The switch to the panel of predicted words is done after exceeding the attention of meditation threshold (depending on settings). This operation is performed less frequently than the selection of a key, so it was possible to apply the method, which requires more time and is more prone to errors. Appropriate concentration or meditation time period above the threshold was determined for the experiments needs.

5 Experiments

Provided experiments involved twelve Polish-spoken volunteers aged 20-47 years of both sexes. They had not used that kind of BCI before. Texts used in studies should be moderate in length, easy to remember, and representative of the target language [11]. Very often they are pangrams. For the user evaluation the pangram in Polish language without diacritical characters was chosen:

ICH DALEKOPIS FALSZUJE GDY PROBY XQV NIE WYTRZYMUJE

The sentence consists of 8 words built of 44 characters separated by 7 white spaces. The experiments used a dictionary containing the 5000 most common Polish words. For simplicity, Polish diacritical characters had been removed.

The maximum time between blinks in a double blink was experimentally set to 600ms. After preliminary test we had also determined that the period time t_p between change of keyboard section (time for the user's decision and double blink) should be set to 1.5s. Table 1 presents results of the experiment ($time$ - in seconds, err_k - number of incorrectly selected keys), when the users typed the pangram without support of predicted words. Calculated text entry factors are: $CPM = 5.52$, what is about $WPM = 1.11$ (considering that 1 word is equal to about 5 characters for English text), calculated MSD error rate [22] equals 7.03%.

Table 1. Typing without words prediction.

user	trial 1		trial 2		trial 3		trial 4		trial 5		avr	
	$time$	err_k	$time$	err_k	$time$	err_k	$time$	err_k	$time$	err_k	$time$	err_k
1	550	6	687	11	617	7	532	4	525	4	582.2	6.4
2	532	3	580	6	518	2	646	4	510	3	557.2	3.6
3	565	5	523	3	510	2	494	1	501	3	526.6	2.8
4	619	7	600	8	678	6	550	7	554	4	580.2	6.4
5	580	3	567	4	545	2	530	2	543	1	553.0	2.4
6	524	2	520	3	523	2	533	5	510	2	522.0	3.0
7	623	7	608	7	611	6	592	6	560	3	598.8	5.8
8	578	4	533	3	537	2	549	3	543	2	548.0	2.8
9	534	3	521	1	509	0	511	1	521	1	519.2	1.2
10	593	8	550	3	534	2	533	3	540	2	550.0	3.6
11	542	3	529	0	521	0	529	1	525	0	529.2	0.8
12	576	6	551	4	552	4	538	2	542	5	551.9	4.2

Although the keyboard can be calibrated in any moment, for the experiment including predicted words, we decided to set the attention and meditation thresholds manually to study its influence. Their values were selected after preliminary observations. Too low threshold caused accidental switches to the mode of predicted words. Too high value caused problems with maintaining a sufficiently high level for a certain period of time. After initial tests we decided to set the required period over the attention and meditation threshold should be equal to 3 seconds. Next tables (Table 2 and Table 3) presents results, when the key typing is supported by the predicted words. The attention threshold thr_A and meditation threshold thr_M range were set to 60-80. It was selected after preliminary observations. The value of err_k was very similar to the previously obtained, so it is replaced by err_s - number of incorrect switches to the list of predicted words.

Unfortunately, only three words of the pangram belong to the dictionary (ICH, GDY, NIE), but they have taken first places on the lists, and consequently they were quickly selected together with the whitespace at the end. The best results were obtained for thr_A equals 65 ($WPM = 1.21$) and thr_M equals 80 ($WPM = 1.27$). The average number of unexpected switching err_{avr} to the list of predicted words was decreased when the thresholds were increased. In the case of $thr_M = 80$ only one of users had accidental switches to the mode of predicted words.

Table 2. Typing with words prediction and attention threshold.

user	$thr_A = 60$		$thr_A = 65$		$thr_A = 70$		$thr_A = 75$		$thr_A = 80$	
	$time$	err_s	$time$	err_s	$time$	err_s	$time$	err_s	$time$	err_s
1	575	2	539	1	601	2	631	1	689	0
2	615	3	535	2	621	2	605	1	715	1
3	490	1	470	1	512	2	492	0	553	0
4	469	1	512	2	554	1	561	1	654	0
5	450	1	466	0	462	0	476	0	609	0
6	510	2	489	1	521	1	504	1	581	0
7	498	2	478	1	480	1	510	0	543	0
8	512	1	515	1	510	1	520	1	573	0
9	602	4	589	2	580	2	590	1	595	2
10	534	2	512	1	487	1	492	0	546	0
11	489	2	474	1	498	0	497	0	512	0
12	521	1	501	1	510	2	545	0	601	0
avr	521.1	1.83	506.7	1.17	528.0	1.25	535.3	0.5	597.6	0.25
WPM	1.17	-	1.21	-	1.16	-	1.14	-	1.02	-

Table 3. Typing with words prediction and meditation threshold.

user	$thr_A = 60$		$thr_A = 65$		$thr_A = 70$		$thr_A = 75$		$thr_A = 80$	
	$time$	err_s	$time$	err_s	$time$	err_s	$time$	err_s	$time$	err_s
1	542	2	563	2	492	1	483	0	455	0
2	532	2	511	1	489	1	465	0	476	0
3	474	1	451	0	485	1	491	1	546	0
4	487	1	484	1	501	1	497	0	496	0
5	499	1	487	1	476	0	498	0	464	0
6	512	1	472	0	522	1	503	1	462	0
7	501	1	480	1	494	1	475	0	478	0
8	521	2	502	1	498	0	503	0	482	0
9	487	0	488	0	475	0	478	0	473	0
10	534	3	541	3	520	1	501	1	507	1
11	476	0	487	1	479	0	467	0	464	0
12	489	1	469	0	476	0	479	0	469	0
avr	504.5	1.25	494.6	0.92	492.3	0.58	486.7	0.25	481.0	0.08
WPM	1.21	-	1.24	-	1.24	-	1.26	-	1.27	-

6 Discuss

The time of the single key selection depends on number of the time periods t_p representing the interval of keyboard section change. Provided studies used $t_p = 1500ms$. This time period includes the time for the user's decision about the selection and the time of double blink t_{db}. Assuming the user needs full t_p time for decision and blinking, it gives i.e. $3t_p$ to insert "A", and $7t_p$ to insert "R", because sequentially highlighted are: 3 rows, 2 groups (in the third row), 2 keys (in the second group of the third row). Therefore, the arithmetic average time of character insertion (including a space key) is $6.22 * t_p$. However, it is $6.51 * t_p$ for the pangram used for studies. After simple calculation we get the longest faultless expected time of entry the pangram. It equals $498s$ ($WPM = 1.23$).

On the other hand the users can blink immediately when the required row, group of keys or a key is highlighted. The sequence of keys is easy to remember (in our research tool it is alphabetical order), the experienced user will know in advance when he has to blink. Since each key is reached after three double blinks, then three of t_p periods can be shortened to $3t_{db}$. Hence, i.e. the user needs $3t_{db}$ to insert "A", and $4t_p + 3t_{db}$ to insert "R". The duration of a single eye blink is 100-400ms [1], double eye can be max. 800ms. During studies we assumed, that 600ms will be sufficient t_{db} period for non-accidental double eye blink. Repeating the calculation, this time the arithmetic average time of character insertion is $3.22 * t_p + 3 * t_{db}$. However, for the pangram used for studies it is $3.51 * t_p + 3 * t_{db}$. Hence, we get the best possible time of the pangram entry equals $360.3s$, ($WPM = 1.7$).

Summarizing, expected users results of typing without words prediction should be in the range 360.3-498 seconds. The only one test result (third user in forth trial) belongs to this range (Table 1). However, we need to remember the users were beginners without experience in such kind of HCI. They made many delays: they selected incorrect keyboard sections by accidental double blink or thought too long exceeding the time of highlighting. Considering this, the obtained results can be estimated as satisfactory. We can expect some improvement after long term training.

Going further and having regard to experienced users, every t_p period can be set to t_{db} value. Then the text entry speed for the pangram can grow to $WPM = 3.15$. It corresponds to 3.8 seconds per key selection. Such kind of interaction does not need the EEG support in the form described in this paper. However, such solution (with the very short time for user interaction) would be hard to use resulting in many errors, and consequently would cause reduced efficiency.

7 Conclusions

Proposed touchless keyboard uses eye double blinks. The obtained result during evaluation is $WPM = 1.11$ with the MSD error rate equals 7.03%. In the area of such kind of text entry systems, this result is good, although after theoretical calculations we expected the value of non-error writing in the range of $1.23 - 1.7$.

Controlling the keyboard with the blinks can be supported by EEG signals. This is the novelty in the proposed approach. The results of experiments show that the best mode is the mode using meditation threshold of 80. It achieves efficiency of 1.27 WPM, but we should note that the words prediction was used. Selecting the meditation as a parameter for the mode of predicted words, the number of errors is lower in comparison to the experiment using attention. This is due to the fact that when using the application, the user unwittingly focused on the action, eg. the selection of the letters, which can inadvertently changes the mode of application. Whereas a longer meditation above the threshold can be easy achieved by closing eyes, which is done only for the intended purpose.

It is also possible to introduce improvements in the keyboard. The *Divide and Conquer* algorithm could be used breaking down a set of keys into two subsets every time. However, it would involve the reconfiguration of the number of rows and columns, which could not be comfortable in use. Next, the order of keys could be dependent on the frequency of corresponding characters in the national language. Such HCI solution would require high activity of eyes, which could be very uncomfortable for the user. During studies, after only first attempt, most users complained of eye strain.

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