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Project and evaluation EMG/EOG human-computer interface

Abstract. *In this paper we present Electromyography/Electrooculography (EMG/EOG) speller. It allows users to write sentences or phrases using blinking exclusively. Eye blinks are detected through simple threshold method. Moreover, the speller is comfortable to use. We based it on Open Source software available for free, as well as low-cost OpenBCI hardware. We measured the performance of the interface in an experiment. The results showed that: (1) symbols were recognised at 90% accuracy rate; (2) 100% of eye blinks was detected; (3) Information Transfer Rate (ITR) we achieved equaled 43,3 bit/min.*

Streszczenie. *W artykule zaprezentowano interfejs człowiek-komputer wykorzystujący Elektromiografię i Elektrookulografię. Interfejs umożliwia pisanie jedynie za pomocą wykrywanych mrugnięć. Do ich wykrywania zastosowano prostą detekcję progową. Ponadto, interfejs jest wygodny w użyciu. Bazuje on na darmowym oprogramowaniu Open Source i tanim urządzeniu OpenBCI. Przeprowadzono eksperyment testujący możliwośći interfejsu. Uzyskano następujące rezultaty: (1) 90% skuteczności w rozpoznawaniu znaków; (2) 100% skuteczność w detekcji mrugnięcia; (3) Współczynnik Information Transfer Rate (ITR) wyniósł 43,3 bit/min**(Projekt i ewaluacja interfejsu człowiek komputer wykorzystującego EMG/EOG)***

Keywords: HCI, speller, EMG, EOG, OpenBCI, Open Source
Słowa kluczowe: HCI, speller, EMG, EOG, OpenBCI, Open Source

Introduction

Human Computer Interfaces (HCI) allow users to send to and receive informations from the machine. The HCI varies in methods and areas of application. Best known examples of HCI are computer peripherals like keyboard or monitor used for everyday interaction with personal hardware. However, there are also more complicated techniques that allows hand-free control over the machine (e.g.: brain waves based interfaces, virtual reality and eye-tracking). Among possible applications of these methods we can distinguish: medical [1, 2], educational [3, 4] or military [5] purposes. Here we would like to focus on the first mentioned utilization.

One particular example of usefulness of HCI is that it can serve as a medium of communication for patients with neurodegenerative diseases, like amyotrophic lateral sclerosis (ALS) [6]. These patients have limited or no contact with surrounding environment. Highly specialized devices allowing human-computer interaction are created for them. One of these solutions is Brain Computer-Interface (BCI), which measures electrical activity of the brain. Unfortunately, the distribution of brain activity depends on interindividual differences [7, 8]. Because of that mentioned interfaces require special design and user training. It turns out that not all people are able to use them [9]. The computer is not always able to learn how to recognize the intent of the subject with high efficiency, not to mention the costs of this kind of software and hardware.

That's why, if patients can volitionally control at least one muscle, it is recommend to use other ways to communicate. Among these alternative techniques are programs based on measurements of eyeball movements or blinking analysis. The latter often involves spelling single letters or numbers. User watches a matrix of signs, from which one is then chosen [10]. The signal is measured from the eyes region to be analyzed using the computer.

In this article we present a highly efficient low-cost speller, which uses simple bioamplifier to measure eye blinks. Program created for this study is Open Source software and it is available online for anyone interested in testing or adapting our solution.

Materials and Methods

To acquire data we used OpenBCI board. OpenBCI is 8 channel EEG (using amplifier ADS1299, produced by Texas Instruments, and 8-bit microcontroller Atmega328P). Main electrode was placed on FPz (10-20 standard) with reference electrode at earlobe (see figure 1) [11].

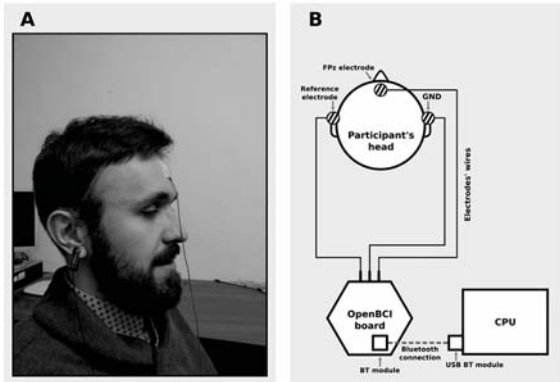

Fig. 1. Electrodes positioning and montage. A. Picture taken with electrodes placed on the participant's forehead (FPz in 10-20 standard) and earlobes (one of them visable on the picture). B. Schematic representation of the hardware configuration required for the EOG/EMG device.

Python was our primary programming language with Linux-based Debain being the operating system of our choice. Core code for communicating with the board and reading the data was based on the software provided by the developer ($https://github.com/OpenBCI/OpenBCI\_Python$). After some modifications of the adapted class (with additional Python modules like Scipy or Numpy [12, 13]) we build a simple API for our speller. Graphical interface was created using Python's PsychoPy package [14]. Our application allows: acquiring, processing and detecting blink artifacts in real time. Therefore it can be used for the speller purposes.

Raw signal was preprocessed using 4th order Butterworth filter (first band-stop 49-51 Hz, then 1-50 band-pass). Blink detection method used was threshold classifier. This is a very simple yet efficient way of exposing extensive signal fluctuations. If the acquired signal exceeds some constant voltage value (e.g. 50 μV), then the blink is detected (see figure 3). After that the signal is expected to cross 0 μV value in order to allow the algorithm to detect another blink artifact. Even when a subject closes and opens eyes very frequently all blinks are successfully detected using this method. The schematic version of the real-time processing workflow is depicted in figure 2.

All code created or modified by us is available at a GitHub repository: $https://github.com/mikbuch/pyseeg$.

We conducted an experiment to test performance of our

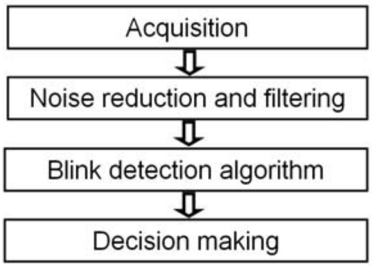

Fig. 2. Block diagram showing the processing steps

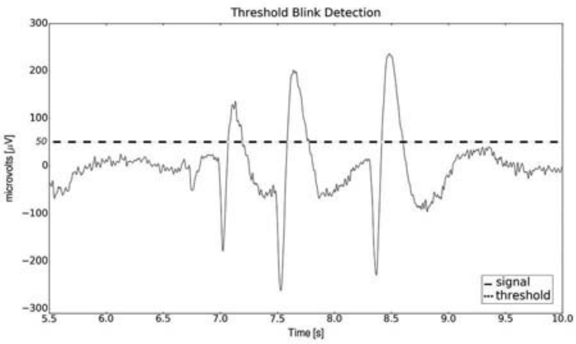

Fig. 3. Detecting blinks using threshold algorithm. When the signal exceedes fixed threshold a blink event is sent to the speller interface

speller. 14 healthy volunteers were asked to spell single phrase using our interface. Beside one participant, none of them had any previous experience with using hand-free spellers. Matrix of signs (5x5) was presented on the 19 inch screen (see figure 4). The matrix was inspired by the one proposed by Donchin [10].

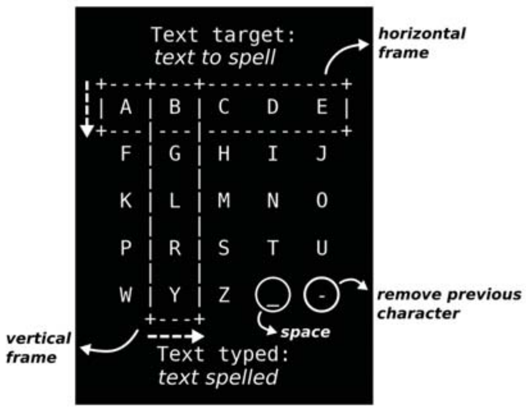

Fig. 4. Interface description. The matrix consisted of 25 signs including special characters like "remove" and "space". Two frames switched for rows and then for columns (for examplary procedure see Fig. 5). On this figure *italized* text, circles and arrows are part of the description, not speller itself. Dashed arrows indicate rows/columns switching direction

Now we are going to describe the procedure of choosing a sing from the matrix. At the beginning row after row was marked for 500 ms (figure 5A). Participant had to blink to stop the rows switching, then the chosen row remained marked. Next, the same process took place for the columns (figure 5B). The letter spelled was the letter at the intersection of the marked row and column (figure 5C).

The experiment consisted of two parts. The first stage was training phase. The task in this phase was to spell “YELLOW_ZEBRA”. The idea of the training phase was that the subjects would learn how to use the speller and what are its limitations. We could manipulate threshold of blink detection individually for each participant (signal amplitude during blinking varies interindividually). Results for the training session were not recorded. The second, and main, part was similar to the first one, except there was other phrase to spell, namely: “ORANGE_JUICE”. Results of this phase were recorded. Both phrases consisted of 12 characters. After the experiment the subjects were asked to evaluate usefulness, usability, enjoyment of our solution with single grade in range 1-5 where 1 was very bad experience and 5 was an excellent device.

We analyzed separately the performance of our interface during spelling task and an algorithmical blink detection. The spelling accuracy is the ratio of the correctly spelled characters (including appropriate usage of the *backspace* sign) to all characters spelled. By correctly chosen letter we understand two consecutive correct blinks: first for the row and the second for the column. If any of these (row or column) was inaccurately chosen (i.e. the participant blinked too fast or too late – when the frame was not in the right position) then both decisions (blinks) for this character were considered the wrong answer (counted as one error). In that case the subject had to delete the character that was incorrectly inputed by spelling. Notice that the similar situation would take place for the incorrectly chosen *backspace* – then the participant would have to spell the letter deleted by mistake one more time. The scores from this task for the particular subject, taken the rules described above, could be as follows: (1) 12/12 – 100% – perfect run; (2) 13/14 – 93% – one letter chosen by mistake, but correctly deleted afterwards; (3) 14/16 – 88% – two wrongly spelled signs, both deleted (and the correct ones inserted in their place); (4) 15/18 – 83 %; etc. In addition to the accuracy score we also calculated Information Transfer Rate (ITR) for our speller (for the actions of the participants).

Blink detection accuracy is the capability of our algorithm to correctly detect blinks (volitional as well as spontaneous) in the acquired signal.

Results

Two subjects were excluded from analyses. Despite training session, it took them significantly more time ($t = -6.61$, $p < 0.001$) than the rest of the participants to spell the phrase (more than 2 minutes to write 12 characters, while all the other participants finished spelling in less than 90 seconds).

Our speller performed with a very high accuracy in spelling signs (90%, see figure 6., green bars). Mean time for spelling all 12 characters was 66 seconds (table 1) which gives 5,5 second per sign. ITR was also calculated for the speller, it is 43,3 bpm (figure 7).

All blink samples were correctly classified. Algorithm did not classified any non-blink samples as participant’s blink. Therefore our threshold algorithm accuracy in blinking detection was 100% for all subjects (figure 6, red bars). Evaluation after the experiment showed that our solution had very high (85%) score of general satisfaction and usability.

Discussion

Our results generally are similar or better than these achieved by other authors [15, 16, 17, 18, 19, 20, 21]. We find it hard to compare accuracy results directly because of various methods of accuracy evaluation, i.e. it is not always clear whether lower speller accuracy is due to human error (e.g. insufficient training) or rather not optimal algorithm applied for blinking detection (it can be too sensitive and detect

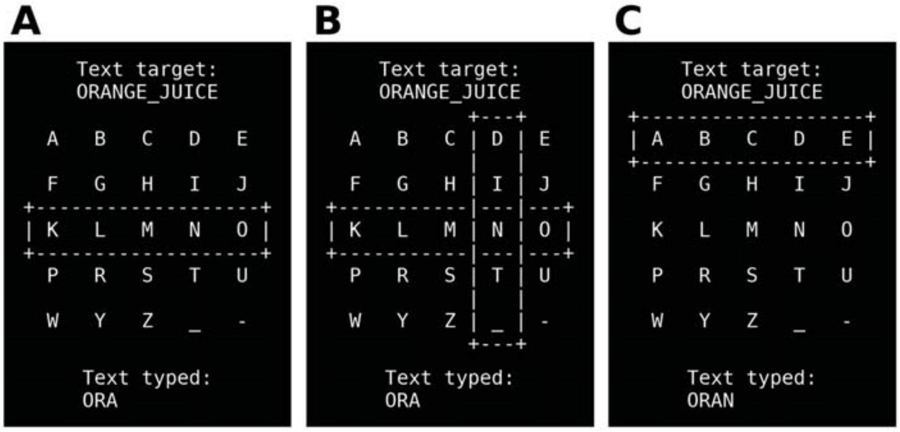

Fig. 5. Procedure of choosing a character. First horizontal frame swiches rowes from top to bottom every 500 ms. (A). Then, after user's blink, the horizontal frame stops and a vertical frame appears and starts switching columns from left to right (B). After the second blink sign at the intersection of frames is typed

Table 1. Results for particular subjects: accuracy of the spelling process, time required to spell experimental phrase, ITR and evaulation score

Subject	Accuracy [%]	Time to recognition [s]	ITR [bits/min]	Evaluation [-]
sub_001	100	55,2	60,6	3
sub_002	83	86,3	26,9	4
sub_003	93	47,5	59,8	4
sub_004	93	45,5	62,4	4
sub_005	93	51,7	55,0	5
sub_006	88	68,2	37,2	5
sub_007	83	76,2	29,2	4
sub_008	83	84,1	27,6	5
sub_009	83	83,9	27,7	5
sub_010	93	66,8	42,6	4
sub_011	88	66,1	38,4	4
sub_012	93	66,0	43,0	4
mean	90	66,5	43,3	4,3

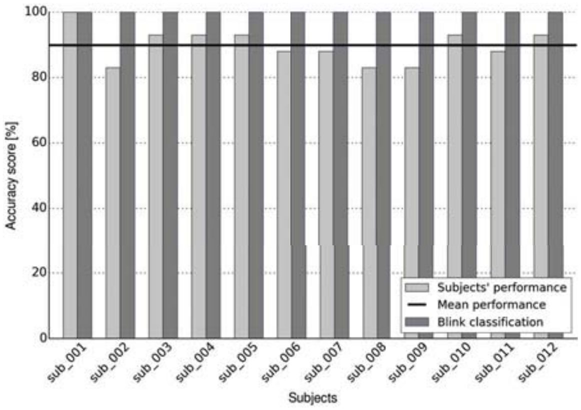

Fig. 6. Accuracies for blink detection and user decision for particular subjects. Green bars indicate individual subjects' performance, whereas blue ones show classification accuracy of the threshold blink detection algorithm. Red line is arythmetical average across subjects' performance (i.e. average green bar height)

facial muscles contraction as blinking or otherwise, not to detect some of the volitional blinks of the participant). Main advantage of our solution is shorter period of time required to write a sentence. Moreover subjects learn how to use our EOG based speller relatively quickly. ITR is high and equivalent to other scientists' research.

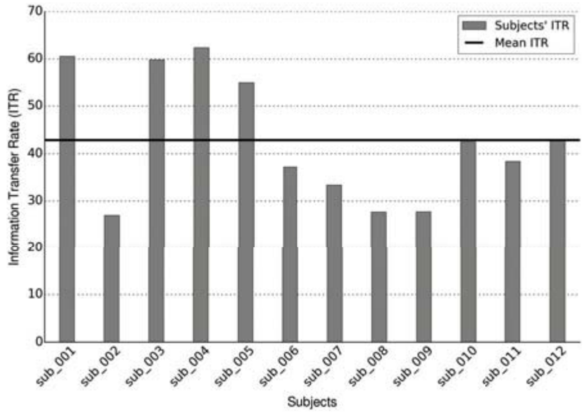

Fig. 7. Information Transfer Rate for all subjcts (green bars). Red horizontal line represents mean ITR across all subjects

The exclusion of the two participants shows that although for the majority of the examined population this device is quite straightforward and easy to use, there are some individuals which either require some additional practice or just are unable to use spellers based on eye-blinks. Nevertheless as we mentioned earlier accuracy result at 90% for the 85% of the population (12 out of 14 in our case) are still higher than these in the case of BCI [9]. Besides, usually the training sessions take less time and effort using the EOG/EMG approaches.

High evaluation result tells us that our solution is pleasant and easy to use (for people who are able to use it at all). It took relatively short period of time to prepare hardware (only 3 electrodes) and to go through the training session. After that our subjects were ready to reliably spell signs with their eyes blinks. This kind of assessment is a novum compared to other studies in which blink-based interfaces were presented (we find it quite odd that the participants are so rarely asked about their personal opinion of the tool they have just been using). The reason for this may be that for the people, who would use such devices on daily bases, the solution itself significantly increase the quality of life. However there is no doubt that some interfaces are easier and more pleasant to use than the others.

Conclusion

The solution we presented in this paper is both reliable and economic. It is based on low-cost hardware and open-source software. Furthermore our speller is efficient and easy to use after even a brief learning. We hope that interfaces introduced for medical and rehabilitational purposes (like these for people with limited volitional muscles control) will become cheaper and easier to obtain for all who are in need. Our work shows that this goal is achievable.

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