HAPTIC BCI PARADIGM BASED ON SOMATOSENSORY EVOKED POTENTIAL

TOMASZ M. RUTKOWSKI1,2, HIROMU MORI3, YOSHIHIRO MATSUMOTO3, ZHENYU CAI3, MOONJEONG CHANG3, NOZUMI NISHIKAWA1, SHOJI MAKINO3, AND KOICHI MORI3

ABSTRACT. A new concept and an online prototype of haptic BCI paradigm are presented. Our main goal is to develop a new, alternative and low cost paradigm, with open-source hardware and software components. We also report results obtained with the novel dry EEG electrodes based signal acquisition system by g.tec, which further improves experimental comfort. We address the following points: a novel application of the BCI; a new methodological approach used compared to earlier projects; a new benefit for potential users of a BCI; the approach working online/in real-time; development of a novel stimuli delivery hardware and software. The results with five healthy subjects and discussion of future developments conclude this submission.

1. INTRODUCTION

The state of the art BCI relies mostly on visual and imagery paradigms [1], which require longer training or good vision from the subjects. Many late stage ALS suffering patients have weaker or lost sight. Thus, as the the alternative BCI solutions, the auditory [2] or haptic (somatosensory) modalities [3, 4] are proposed in order to enhance brain-computer interfacing comfort or to boost information transfer rate (ITR). A concept of somatosensory (haptic) modality creates a very interesting possibility to target tactile sensory domain, which is not as demanding as vision during operation of machinery or visual computer applications. A potential somatosensory BCI paradigm is thus less mentally demanding. The first successful trial to utilize responses to somatosensory stimuli utilized steady-state ones [3] with lower frequencies exciting mostly Meissner-endings of human finger tips [4]. There is also a very recent development with somatosensory ERP based paradigm using tactile Braille stimulators creating static “push-stimuli” [4]. We propose to target the higher tactile stimulating frequencies in form of 10ms long bursts to stimulate Pacini-endings [5]. Such stimulus creates “a quick touch sensation” delivered through tactile exciters as depicted in Figure 1. The concept is perfectly suited for a P300 response based BCI paradigm design.

2. METHODS

The report results with the haptic BCI paradigm are based on the g.MOBIlab+ portable eight channels EEG amplifier and the g.SAHARA dry electrodes set by g.tec. The eight dry EEG electrodes have been placed at the Cz, CPz, POz, Pz, P1, P2, C3, and C4 sites. The reference and ground were attached with ECG disposable wet electrodes behind both subject’s ears. The EEG signals were sampled at 256Hz. The five male, right handed subjects participated voluntarily (ages 22 – 42, mean 31). For the EEG signal acquisition, stimulus triggering and response classification, an open source BCI2000 [6] system was chosen due to its flexibility and future “no-cost” application for patients in needs. The BCI2000 system was set in P300 stimuli delivery and processing mode with the following parameters:

(1) EEG high–pass and low–pass filters set to 0.1Hz and 25Hz respectively. Notch filter set for a 50Hz frequency stopping.
(2) stimulus length set to 10ms delivered from the Arduino UNO:
(3) stimulus onset asynchrony of 250ms;
(4) epoch length set to 800ms;

Figure 1. The haptic BCI prototype with four tactile exciters positioned on a sponge to cancel a possible acoustic feedback.
(5) epochs to average: 5 to 8 - subject performance dependent.

We tested LDA and Stepwise Linear Regression classifiers. The both resulted in similar outcomes. In this submission we report results with the latter one.

The stimulus delivery application was designed based on an open-source Arduino UNO [7] microcontroller connected via USB port to the host computer with a custom programmed communication software allowing vibrotactile stimuli delivery. We focus on the future portable and bedside application development. The four tactile exciters (Hi-Wave HIAx19C01-8: 19mm; metal cup; 8Ω), as depicted in Figure [1] were connected to digital outputs. The 10ms square wave bursts with frequency of 1000Hz were delivered as stimuli. The resulting square-wave-shape stimuli delivered “the quick touch sensation” for easier perception, as reported by the subjects.

The messages from the BCI2000 to the haptic application were sent via UDP port with triggers delivered to the custom patch developed in a Arduino UNO board using serial communication protocol.

During the experiments subjects were instructed, as in classical P300 based oddball paradigms, to attend to a single finger tactile stimuli while ignoring the other three. Each finger had assigned a number 1 – 4. Exactly the same number of vibrotactile bursts were delivered in a random order to each finger of the subject dominant hand and the subjects were instructed to choose (“spell”) the numbers as in usual “copy spelling mode.”

3. RESULTS AND CONCLUSIONS

The results from our preliminary experiments with five healthy subjects are summarized in Table 1. The single subject was able to hit the maximum accuracy of 100% while the remaining three were above a chance level of 25%. Testing the system with ALS patients is next on our agenda together with the improvement and optimization of the stimulation. The already obtained results have been comparable to [1], or even better if we take into account the number of averages to reach the performance, and the number of electrodes used with our portable setting.

The reported possibility to combine open-source projects of the Arduino UNO and the BCI2000, together with compact EEG acquisition g.MOB1lab+ & g.SAHARA hardware by g.tec is a step forward in development of the new portable, vision-free tactile BCI.

Table 1. Peak interfacing accuracies (chance level 25%) and maximum bit–per–run–rate (BPRR) of 17.14 bit/min. The experiments conducted in the first session/day mode for subjects # 2 – 5. The subject # 1 was more experienced.

| subject | max accuracy | BPRR [bit/min] |
|---------|--------------|----------------|
| #1      | 100%         | 17.14          |
| #2      | 75%          | 7.92           |
| #3      | 50%          | 1.56           |
| #4      | 50%          | 2.49           |
| #5      | 75%          | 5.94           |

ACKNOWLEDGMENTS

This research was supported in part by a grant for “Research and development of brain machine interface (BMI) using the acoustic spatial information for ALS patients” within the scope of the Strategic Information and Communications R&D Promotion Programme no. 121803027 of The Ministry of Internal Affairs and Communication in Japan.

REFERENCES

[1] J. Wolpaw and E. W. Wolpaw, eds., Brain-Computer Interfaces: Principles and Practice. Oxford University Press, 2012.

[2] T. M. Rutkowski, “Auditory brain–computer/machine interface paradigms design,” in Haptic and Audio Interaction Design (E. Cooper, V. Kryssanov, H. Ogawa, and S. Brewster, eds.), vol. 6851 of Lecture Notes in Computer Science, pp. 110–119, Springer Berlin / Heidelberg, 2011.

[3] G. Muller-Putz, R. Scherer, C. Neuper, and G. Pfurtscheller, “Steady-state somatosensory evoked potentials: suitable brain signals for brain-computer interfaces?,” Neural Systems and Rehabilitation Engineering, IEEE Transactions on, vol. 14, pp. 30–37, March 2006.

[4] M. van der Waal, M. Severens, J. Geuze, and P. Delsing, “Introducing the tactile speller: an ERP-based brain-computer interface for communication,” Journal of Neural Engineering, vol. 9, no. 4, p. 045002, 2012.

[5] R. S. Johansson and J. R. Flanagan, “Coding and use of tactile signals from the fingertips in object manipulation tasks,” Nature Reviews Neuroscience, vol. 10, no. 5, pp. 345-359, 2009.

[6] G. Schalk and J. Mellinger, A Practical Guide to Brain–Computer Interfacing with BCI2000. Springer-Verlag London Limited, 2010.

[7] http://arduino.cc/ [7] “Arduino - an open-source electronics prototyping platform.” 2012.

[8] http://cycling74.com/ “Max 6,” 2012.

[9] S. Halder, M. Rea, R. Andreoni, F. Nijboer, E. Hammer, S. Kleih, N. Birbaumer, and A. Kübler, “An auditory oddball brain–computer interface for binary choices,” Clinical Neurophysiology, vol. 121, no. 4, pp. 516 – 523, 2010.

URL: http://about.bci-lab.info