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ABSTRACT

A highly-wearable single-channel Brain- Computer Interface (BCI) based on Steady-State Visually Evoked Potentials (SSVEPs) and Augmented Really (AR) is proposed. The SSVEP elicitation is provided by three AR head-mounted displays (HMD), namely Epson Moverio BT-350, Oculus Rift S, and Microsoft HoloLens. Four flickering stimuli, ranging from 8 Hz to 15 Hz, are used. The goal of the work is to carry out a performance comparison of the three aforementioned devices, in terms of stimuli visualization and SSVEPs detection. To this aim, classification accuracy and time response were assessed involving nine healthy volunteers during the experimental activity. The obtained results demonstrate that choosing an adequate HMD to render the flickering stimuli is decisive for obtaining adequate performances.

1. Basic information

Brain-Computer Interfaces (BCIs) are systems aimed at converting the central nervous system (CNS) activity into information, enabling communication between the human brain and artificial devices without the use of muscles or peripheral nerves.

Among all the non-invasive methods used to capture brain signals, electroencephalography (EEG) is certainly the most used [1]. Originally, BCIs based on EEG were applied mostly for rehabilitation purposes, providing a way to assist people with motor disabilities [2]. More recently, the application of BCI has been extended also to non-medical fields, such as gaming [3], industrial inspection [4], fatigue detection [5], etc.

Different paradigms can be used for implementing EEG-based BCIs, depending on the task to be performed by the user and on the brain signal to be decoded. Among these paradigms, Steady-State Visually Evoked Potentials (SSVEPs) represent an interesting solution in terms of Signal-to-Noise Ratio (SNR), Information Transfer Rate (ITR), reproducibility and robustness to artifacts [6]. SSVEPs are exogenous potentials that are induced in the primary visual cortex when the user is observing a flickering stimulus [7]. Generally, the detected SSVEP exhibits a fundamental frequency (at the same value of the targeted frequency stimulus) and often higher harmonics. In SSVEP-based BCI, the system allows the user to perform a selection by simply staring at the related flickering stimulus, as implemented in [6], where the movement of an humanoid robot was driven by the user by staring at two arrows flickering at different frequencies, associated to Move to left and Move to right commands. In traditional applications, the visual stimuli are commonly generated through light-emitting diodes (LEDs) [8], or liquid crystal display (LCD) monitor [9]. However, these solutions place limits on the mobility and portability of the system.

On the other hand, augmented reality head-mounted displays (AR-HMDs) offer a solution to guarantee flexibility and wearability [10]. In this case, the flickering stimuli are superimposed to the surrounding environment, allowing the user to interact more easily with the real world.

Another goal to pursue in wearable systems is to effectively decrease the number of necessary electrodes (typically eight in traditional EEGs [10]), aiming to improve the use of BCIs in everyday life, still preserving acceptable performance. Single-channel BCIs (with only two electrodes for the differential input and one electrode for the reference), represent a highly-wearable alternative to traditional multi-channel BCIs, strongly reducing complexity and user discomfort without performance degradation [6,11–14].

On the basis of these considerations, in this work, the authors propose a highly-wearable single-channel SSVEP-based BCI, by using AR to generate four concurrent flickering stimuli. The main objective is to evaluate the user experience, in terms of both stimuli visualization and SSVEPs detection, considering three different AR device: Epson Moverio BT-350, Oculus Rift S, and Microsoft HoloLens.

The paper is organized as follows. Section 2 describes the system architecture, focusing on the chosen AR devices, on the acquisition unit and, finally, on the proposed SSVEP detection algorithm. In Section 3, the obtained experimental results are presented. Finally, in Section 4 conclusions are drawn.

2. Description of the AR-BCI system

In this section, the design of the proposed highly wearable single-channel SSVEP-based BCI is presented. In particular, the description of the system architecture, along with the devices used and the proposed detection algorithm, is provided.

2.1. Architecture

The system architecture is shown in Fig. 1. The AR Display, worn by

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Fig. 3. BCI Equipment: a) Olimex EEG-SMT; b) Raspberry Pi4.

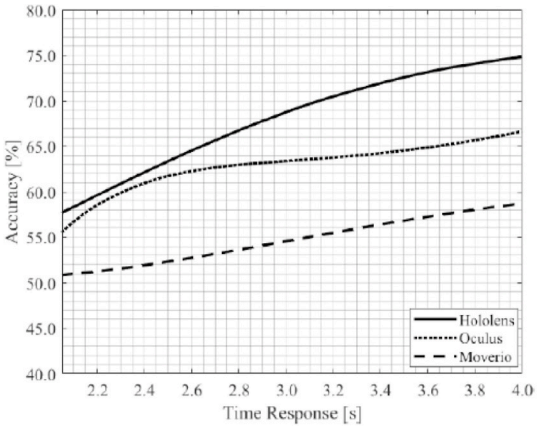

Fig. 4. Accuracy vs Time Response for the three AR devices.

4. Conclusions

This work proposes a highly wearable SSVEP-based single channel BCI, where three different AR HMDs, namely Epson Moverio BT-350, Oculus Rift S (integrated with Zed Mini), and Microsoft HoloLens, were chosen to generate four concurrent flickering stimuli. The main challenge, regarding the performance comparisons between the aforementioned AR devices, was explored. Experimental results demonstrate that choosing an adequate HMD to render the flickering stimuli is crucial for obtaining acceptable performances: the overall user experience, in fact, is strongly dependent on how the flickering stimuli are rendered. With Microsoft HoloLens and Oculus Rift S whose rendering is location-based, the classification accuracy resulted almost 20% larger than the values obtained with Epson Moverio BT-350. On the other hand, some user felt motion sickness effects during the trials with Oculus Rift S, due to the VST technology of the HMD. Considering the large difference of cost between Microsoft HoloLens and the other two selected devices, further work will be carried out to identify the HMDs that could provide an optimal trade-off of cost, ergonomics, and rendering capability, aiming to achieve fully wearable, practical, and affordable systems for daily life, wearable applications [15] in the 4.0 Era context [16].

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References

[1] J.R. Wolpaw, N. Birbaumer, D.J. McFarland, G. Pfurtscheller, T.M. Vaughan, Brain– computer interfaces for communication and control, Clin. Neurophysiol. 113 (6) (2002) 767–791.
[2] A. Biasiucci, R. Leeb, I. Iturrate, S. Perdikis, A. Al- Khodairy, T. Corbet, A. Schnider, T. Schmidlin, H. Zhang, M. Bassolino, et al., Brain-actuated functional electrical stimulation elicits lasting arm motor recovery after stroke, Nat. Commun. 9 (1) (2018) 1–13.
[3] B. Kerous, F. Skola, F. Liarokapis, Eeg-based BCI and video games: a progress report, Virtual Real. 22 (2) (2018) 119–135.
[4] L. Angrisani, P. Arpaia, A. Esposito, N. Moccaldi, A wearable brain–computer interface instrument for augmented reality-based inspection in industry 4.0, IEEE Transactions on Instrumentation and Measurement 69 (4) (2019) 1530–1539.
[5] X. Zhang, J. Li, Y. Liu, Z. Zhang, Z. Wang, D. Luo, X. Zhou, M. Zhu, W. Salman, G. Hu, et al., Design of a fatigue detection system for high-speed trains based on driver vigilance using a wireless wearable EEG, Sensors 17 (3) (2017) 486.
[6] P. Arpaia, L. Duraccio, N. Moccaldi, S. Rossi, Wearable brain–computer interface instrumentation for robot-based rehabilitation by augmented reality, IEEE Transactions on Instrumentation and Measurement 69 (9) (2020) 6362–6371.
[7] Y. Wang, R. Wang, X. Gao, B. Hong, S. Gao, A practical vep-based brain-computer interface, IEEE Trans. Neural Syst. Rehabil. Eng. 14 (2) (2006) 234–240.
[8] X. Gao, D. Xu, M. Cheng, S. Gao, A BCI-based environmental controller for the motion- disabled, IEEE Trans. Neural Syst. Rehabil. Eng. 11 (2) (2003) 137–140.
[9] P. Gergondet, S. Druon, A. Kheddar, C. Hintermüller, C. Guger, M. Slater, Using brain-computer interface to steer a humanoid robot, in: 2011 IEEE International Conference on Robotics and Biomimetics, IEEE, 2011, pp. 192–197.
[10] Y. Ke, P. Liu, X. An, X. Song, D. Ming, An online SSVEP-BCI system in an optical see-through augmented reality environment, J. Neural. Eng. 17 (1) (2020), 016066.
[11] P. Arpaia, E. De Benedetto, L. Duraccio, Design, implementation, and metrological characterization of a wearable, integrated AR-BCI hands-free system for health 4.0 monitoring, Measurement (2021) 109280.
[12] P. Arpaia, E. De Benedetto, C.A. Dodaro, L. Duraccio, G. Servillo, Metrology-based design of a wearable Augmented Reality system for monitoring patient’s vitals in real time, IEEE Sensor. J. 21 (9) (2021) 11176–11183.
[13] P. Arpaia, N. Moccaldi, R. Prevete, I. Sannino, A. Tedesco, A wearable EEG instrument for real-time frontal asymmetry monitoring in worker stress analysis, IEEE Transactions on Instrumentation and Measurement 69 (10) (2020) 8335–8343.
[14] T.-H. Nguyen, W.-Y. Chung, A single-channel SSVEP-based BCI speller using deep learning, IEEE Access 7 (2018) 1752–1763.
[15] R. Schiavoni, G. Monti, E. Piuzzi, L. Tarricone, A. Tedesco, E. De Benedetto, A. Cataldo, Feasibility of a wearable reflectometric system for sensing skin hydration, Sensors 20 (2020) art. 2833.
[16] S. Grazioso, A. Tedesco, M. Selvaggio, S. Debei, S. Chiodini, Towards the development of a cyber-physical measurement system (CPMS): case study of a bio-inspired soft growing robot for remote measurement and monitoring applications, ACTA IMEKO 10 (2) (2021) 104–110.

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