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Impact of local Laplacian Spatial Filters on C-VEP-Based BCI Performance

K. Nair, H. Cecotti
Dept. of Computer Science, California State University, Fresno, CA, USA
2576 E. San Ramon Ave., M/S ST90, Fresno, USA. E-mail: hcecotti@csufresno.edu

Introduction: Brain-Computer Interfaces (BCIs) enable direct communication between the brain and external devices, offering potential for assistive communication [3]. It can be possible only if the brain responses can be reliably decoded over time. Code-Modulated Visual Evoked Potentials (C-VEPs) stand out for their high ITRs and minimal training requirements, leveraging m-sequences to elicit distinct neural responses [1]. However, real-time decoding faces challenges due to the non-stationarity properties of the EEG signal and its low spatial resolution [2]. We compare different Laplacian spatial filters, including weight calculation methods such as $1/d$, $1/d^2$, $1/\log(d)$, and $1/\sqrt{d}$ where d is the orthodromic distance between two sensors, for enhanced signal quality and robust classification techniques, achieving improved accuracy and advancing the potential of non-invasive BCIs [2].

Material, Methods and Results: The study utilized a C-VEP paradigm with stimuli based on 63-symbol m-sequences [1]. EEG data was collected from eight sensors (O_1, O_2, P_z, P_3, P_4, PO_7, PO_8, and O_z) with 13 participants focusing on visual stimuli across five sessions [3]. Preprocessing incorporated Laplacian spatial filtering, enhancing spatial resolution by emphasizing local neural activity [2]. Classifiers (LDA, BLDA, MLP, SVM, and k-nn) were compared using correlation-based features [4]. Testing different Laplacian methods, the $1/d$ weighting approach and a radius of 1 yielded the highest accuracy [2], and SVM showed consistently higher accuracy compared to other classifiers, demonstrating superior signal enhancement and classification performance [4]. These findings underline the critical role of advanced preprocessing and classifier selection in achieving reliable and high-speed BCI's.

Conclusion: This study highlights the effectiveness of Laplacian spatial filtering, achieving an accuracy of 76.0% ± 18.9 with the $1/d$ weighting method and an SVM classifier, compared to a baseline of 59.7% ± 17.3 without Laplacian filtering. The approach shows how the preprocessing steps substantially impact accuracy compared to the type of classifier used.

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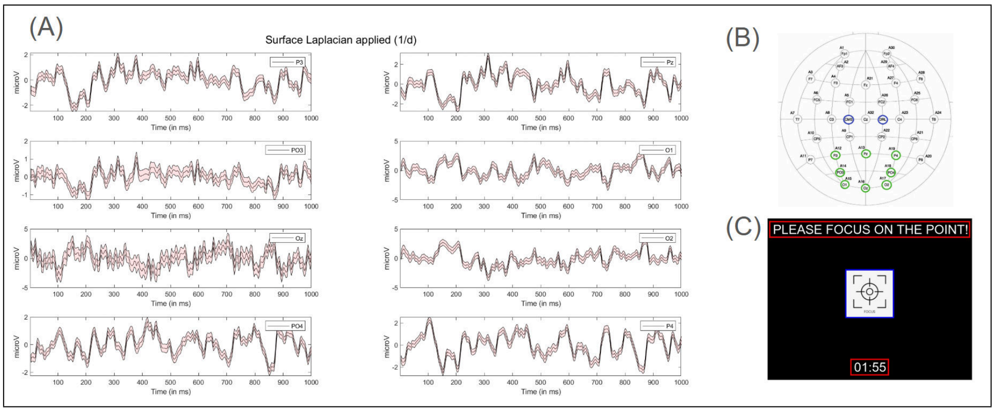

Figure 1: *(A) Time-domain EEG plots showing mean signals with variability bounds, highlighting consistency in neural responses for template-based feature extraction. (B) EEG cap layout highlighting VEP electrodes (green) and ground (blue). (C) Experimental paradigm.*

References:

[1] Ivan Volosyak et al., "Biomed. Phys. Eng. Express 6 035034," 2020.

[2] D.J. McFarland, "The advantages of the surface Laplacian in brain-computer interface research," Int J Psychophysiol, vol. 97, no. 3, pp. 271-276, Sep. 2015, DOI: 10.1016/j.ijpsycho.2014.07.009.

[3] H. Cecotti, "A self-paced and calibration-less SSVEP-based brain–computer interface speller," IEEE Trans. on Neural Sys. and Rehab. Eng., vol. 18, no. 2, pp. 127-133, 2010.

[4] H. Raza, H. Cecotti, Y. Li, et al., "Adaptive learning with covariate shift-detection for motor imagery-based brain–computer interface," Soft Comput., vol. 20, pp. 3085–3096, 2016. doi: 10.1007/s00500-015-1937-5.

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