Reframing Brain-Computer Interfaces as Plug-and-Play Assistive Peripherals for Existing Assistive Technologies

Valentina Caracci [1,2,3*], Angela Riccio [2], Jlenia Toppi [1,2], Simone Boesso [2], Serena Petrinotti [2], Andrea Manni [4], Andrea Caroppo [4], Martina De Paola [4], Alessandro Leone [4], Donatella Mattia [2], Febo Cincotti [1,2]

[1] Department of Computer, Control and Management Engineering, Sapienza University of Rome
Rome, Italy

[2] IRCCS Fondazione Santa Lucia
Rome, Italy

[3] Fondazione Neurone Onlus
Rome, Italy

[4] National Research Council of Italy (CNR), Institute for Microelectronics and Microsystems
Lecce, Italy

* Corresponding author email: valentina.caracci@uniroma1.it

***Abstract*—Severe motor disabilities caused by neurological disorders often prevent individuals from effectively accessing modern Assistive Technologies (AT) for communication and interaction, despite the maturity of commercial AT software ecosystems. Non-invasive Brain-Computer Interfaces (BCIs) can provide alternative access channels by decoding brain activity, yet their adoption in real-world AT contexts remains limited. A key limitation is the prevalent BCI-centered design, which relies on custom software and requires substantial technical support, hindering usability and integration with commercial AT platforms. This paper proposes a conceptual shift, reframing the BCI as a plug-and-play assistive peripheral operating as a standard input device for existing AT software. The proposed architecture is outlined, based on embedded signal processing, automated calibration, and an AT-compatible middleware layer. Finally, a validation strategy grounded in User-Centered Design and collaboration with AT centers is discussed. This contribution addresses key conference topics, including brain-driven sensing devices, augmentative and alternative communication systems, and assistive technologies for people with severe motor disabilities.**

Keywords-Brain-Computer Interface; Assistive Technology.

I. INTRODUCTION

Severe motor disability is a common consequence of a wide range of neurological conditions, including traumatic brain injury, stroke, cerebral palsy, spinal cord injury, and neurodegenerative-muscular diseases. These conditions often result in deeply impaired communication and interaction, affecting quality of life and social participation [1].

In recent years, Assistive Technologies (AT) have evolved, enabling personalized access to mainstream digital communication and interaction through advanced input devices (e.g., eye-trackers, switches, joysticks, alternative keyboards [2]) and customizable software platforms [3]. Commercial AT solutions for communication and computer access have reached a high level of maturity, offering flexibility, robustness, and long-term support. However, for individuals with severe and complex motor impairments, access to such technologies remains an open challenge [4].

Brain-Computer Interfaces (BCIs), particularly non-invasive electroencephalography (EEG) -based systems, can enable communication and interaction by bypassing muscular and peripheral nervous system pathways [5]. Among these, P300-based BCIs, exploiting the P300 Event-Related Potential elicited by infrequent and meaningful stimuli, are widely investigated for communication [1][6]. Despite extensive research evidence supporting their feasibility [1], BCIs are still rarely adopted in real-world AT services. Attempted commercial integration, such as QualiWorld and Brain Painting, has shown potential, but daily use is hindered by low selection speed, EEG cap discomfort, and reliability issues [1][7]. A critical bottleneck involves P300-based control, requiring visual stimuli (e.g., flashing elements) to be overlaid onto interface icons to elicit brain responses [7]. The complexity of implementing this functionality, ensuring its seamless integration with commercial AT software not designed for BCI inputs, is a key limitation to the diffusion of BCIs within standard AT frameworks. This gap between research and AT practice highlights the need for a rethinking of how BCIs are designed, deployed, and integrated into assistive systems.

Most existing BCI-based assistive solutions follow a BCI-centered design, incorporating custom communication interfaces, control applications, and interaction logic. While effective in controlled environments, this paradigm presents several limitations in real-world AT contexts. First, custom BCI software solutions often lack the personalization, flexibility, and usability of mainstream AT platforms [4]. Commercial AT software allows extensive customization of interfaces, access methods, and interaction strategies, essential to accommodate heterogeneous needs and evolving conditions. Second, BCI-centered systems impose a technical burden on users, caregivers, and AT professionals: setup, calibration, troubleshooting, and maintenance require specialized expertise, limiting scalability and sustainability in home and clinical environments. Third, tight coupling between BCI hardware, signal processing, and proprietary software reduces interoperability. This lack of modularity hinders hybrid access strategies and integration with other assistive input devices. These challenges highlight an architectural issue: BCIs are often standalone systems rather than components within an existing assistive ecosystem.

This paper proposes a conceptual and architectural shift to bridge the translational gap between research and everyday AT use: instead of embedding assistive functionalities within BCI systems, BCIs should be designed as plug-and-play peripherals, that integrate seamlessly into

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org

Copyright (c) IARIA, 2026. ISBN: 978-1-68558-370-5

existing AT software environments, without requiring any modification of the AT software itself. Indeed, past attempts to integrate BCIs with commercial ATs (e.g., QualiWorld), required cumbersome multi-machine architectures, such as using two networked laptops to separate BCI and AT processing [7]. The novelty of the paradigm proposed here lies in the elimination of this dependency through an embedded hardware approach. Transforming the BCI into a plug-and-play peripheral with on-board signal processing removes complex setups and reduces PC computational load, enabling a compact and integrated solution.

The rest of the contribution is structured as follows. In Section II, the core idea of the BCI as a plug-and-play assistive peripheral is presented, outlining the conceptual architecture and the validation strategy. In Section III, the work is discussed and future directions are mentioned.

II. Core Idea: BCI as Plug-and-Play Assistive Peripheral

The proposed paradigm reframes the BCI as an assistive peripheral device, analogous to existing AT input devices such as eye-trackers, switches, joysticks, or alternative keyboards [2]. In this approach, the AT software remains unchanged, while the BCI adapts to the AT ecosystem by conforming to standard input modalities already supported by commercial AT platforms. The BCI does not introduce new interaction paradigms at the software level; instead, it translates decoded user intent into conventional input events (e.g., key presses, pointer movements, switch activations). This architectural inversion offers several advantages: *interoperability* – the BCI can be used with any AT software supporting standard input devices; *personalization* – users benefit from the full customization capabilities of existing AT software; *sustainability* – updates, maintenance, and training are aligned with established AT practices. Crucially, this approach aligns with the principle that technology should adapt to the user and their environment, rather than forcing users to adapt to new, isolated systems.

A. Conceptual Architecture

The proposed system architecture is organized into four conceptual layers, as outlined in Figure 1: *i) Signal Acquisition Layer* – non-invasive EEG sensors capture brain signals related to user intention. The design prioritizes usability, comfort, and minimal interference with activities of daily living, enabling long-term use in home environments. *ii) Signal Processing and Intent Detection Layer* – embedded processing units perform real-time signal processing and classification of the P300 feature, leveraging automated calibration and self-adaptive algorithms to address signal non-stationarity. The procedure for setting up, calibrating, and operating the BCI is designed to be straightforward, ensuring that both users and caregivers with limited training can effectively use the device in a home environment. Asynchronous operation and continuous performance monitoring are supported to increase robustness during prolonged daily use and to reduce the need for frequent recalibration. *iii) Intent Abstraction Layer* – detected intentions are mapped to abstract control commands independent of specific AT applications, enabling flexibility and supporting different interaction strategies. This approach facilitates interoperability with heterogeneous AT software and enables future extensions toward hybrid control paradigms (e.g., combining EEG and residual motor inputs). *iv) AT-Compatible I/O Layer (Middleware)* – translates abstract commands into standard input events compatible with commercial AT software. In a real-world use case, the middleware acts as a graphical overlay, allowing for communication between the BCI and the AT software, by managing and synchronizing the BCI stimulation (i.e., stimuli to elicit the P300 are directly overlaid on the user interface) and performing actions on the communication software interface, without requiring the underlying AT software to be rewritten. To overcome the visibility and fatigue issues reported in prior studies [7], the middleware will allow for highly customizable stimulation in terms of shape, color and stimulation speed. The BCI device connects to the user's computer as a conventional input peripheral, and all computationally demanding operations are executed on an embedded platform within the BCI device, minimizing the processing load on the user's computer and enhancing portability.

B. Early Validation Strategy

Validation follows a progressive, user-centered process [1], in collaboration with AT centers, involving professionals and end users. The focus will be on: usability and setup simplicity, including calibration time and caregiver workload; reliability and robustness in real-world settings; user acceptance and perceived benefit, assessed through qualitative feedback. Validation will follow the ISO 9241-210 User-Centered Design framework, evaluating three pillars: *Effectiveness* (targeting the >70% selection accuracy required for satisfactory communication), *Efficiency* (via Information Transfer Rate and the NASA Task Load Index for the perceived cognitive workload), and *Satisfaction* (using the QUEST 2.0 questionnaire to assess AT acceptance and setup) [3][7]. This strategy aims to evaluate not only

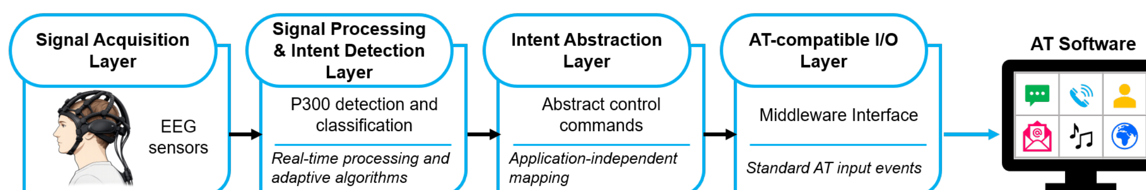

Figure 1. Flowchart of the conceptual architecture of the BCI system as a plug-and-play assistive peripheral device.

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org

technical feasibility, but also ecological validity and integration within established AT service workflows.

III. Discussion, Conclusion and Future Work

This paper introduced a conceptual contribution aimed at mitigating some of the main barriers to BCI adoption in real-world AT ecosystems. Rather than a BCI-centered system, we proposed an architectural shift where BCIs function as plug-and-play peripherals, integrated into existing AT software. The proposed layered modularity inherently supports the clinical principles of Feature Matching (i.e., matching the technology's characteristics to the user's profile) [4]. While currently utilizing EEG and P300, its abstraction allows substituting paradigms (e.g., Steady State Visual Evoked Potentials - SSVEP, Motor Imagery) or sensors to match users' evolving conditions. Furthermore, by ensuring the downstream AT software receives standardized inputs regardless of the brain signal, this architecture enables hybrid control systems, which are highly recommended to improve overall usability [1][7]. Specifically, this approach enhances interoperability, enabling access to a wide range of communication and environmental control functionalities without sacrificing personalization, and improves scalability and sustainability, reducing reliance on BCI-specific solutions. It also supports hybrid access strategies [8], enabling BCIs to complement, rather than replace, other assistive input devices according to user abilities, preferences, and context. At the same time, challenges remain. Mapping brain signals to standard inputs involves trade-offs between generality and performance, while robustness across heterogeneous conditions and long-term usage remains a central technical issue, even with automated calibration and adaptive algorithms.

From a user-centered perspective, the proposed approach emphasizes the importance of aligning BCIs with existing AT practices, and collaboration with AT professionals and end users is therefore essential not only for usability validation, but also for defining meaningful success criteria, acceptable trade-offs, and realistic deployment scenario.

In conclusion, reframing BCIs as assistive peripherals within established AT environments represents a promising direction to bridge the translational gap between BCI research and everyday assistive practice. By prioritizing interoperability, personalization, and sustainability, this approach has the potential to make BCIs a viable and inclusive access option for individuals with severe communication and interaction impairments.

Acknowledgment

The present work was partially supported by the Italian Ministry of Health (PNRRPOC-2023-12377627) and Sapienza University of Rome (LEAF 2024-RM123188F229EC72; Avvio alla Ricerca 2025-AR125199BE5D0A07).

Reference

[1] A. Riccio *et al.*, “Chapter 12 - Interfacing brain with computer to improve communication and rehabilitation after brain damage,” in *Progress in Brain Research*, vol. 228, D. Coyle, Ed., in Brain-Computer Interfaces: Lab Experiments to Real-World Applications, vol. 228. , Elsevier, 2016, pp. 357–387. doi: 10.1016/bs.pbr.2016.04.018.

[2] P. Nisbet, “Integrating assistive technologies: current practices and future possibilities,” *Med. Eng. Phys.*, vol. 18, no. 3, pp. 193–202, Apr. 1996, doi: 10.1016/1350-4533(95)00068-2.

[3] R. Andrich, N.-E. Mathiassen, E.-J. Hoogerwerf, and G. J. Gelderblom, “Service delivery systems for assistive technology in Europe: An AAATE/EASTIN position paper,” *Technol. Disabil.*, vol. 25, no. 3, pp. 127–146, Aug. 2013, doi: 10.3233/TAD-130381.

[4] K. M. Pitt, J. S. Brumberg, and A. R. Pitt, “Considering Augmentative and Alternative Communication Research for Brain-Computer Interface Practice,” *Assist. Technol. Outcomes Benefits*, vol. 13, no. 1, pp. 1–20, 2019.

[5] J. R. Wolpaw, J. del R. Millán, and N. F. Ramsey, “Chapter 2 - Brain-computer interfaces: Definitions and principles,” in *Handbook of Clinical Neurology*, vol. 168, N. F. Ramsey and J. del R. Millán, Eds., in Brain-Computer Interfaces, vol. 168. Elsevier, 2020, pp. 15–23. doi: 10.1016/B978-0-444-63934-9.00002-0.

[6] A. Riccio *et al.*, “On the Relationship Between Attention Processing and P300-Based Brain Computer Interface Control in Amyotrophic Lateral Sclerosis,” *Front. Hum. Neurosci.*, vol. 12, May 2018, doi: 10.3389/fnhum.2018.00165.

[7] C. Zickler *et al.*, “A Brain-Computer Interface as Input Channel for a Standard Assistive Technology Software,” *Clin. EEG Neurosci.*, vol. 42, no. 4, pp. 236–244, Oct. 2011, doi: 10.1177/155005941104200409.

[8] J. del R. Millán *et al.*, “Combining Brain–Computer Interfaces and Assistive Technologies: State-of-the-Art and Challenges,” *Front. Neurosci.*, vol. 4, Sep. 2010, doi: 10.3389/fnins.2010.00161.

Courtesy of IARIA Board and IARIA Press. Original source: ThinkMind Digital Library https://www.thinkmind.org