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Integration of AI with neural interfaces to enhance prosthetic control and user experience

T. Prathiba, S.Nisha Rani, R.Rajprabu
Kamaraj College of Engineering and Technology
(An Autonomous Institution),

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[1]T. Prathiba, Associate Professor, Department of ECE, Kamaraj College of Engineering and Technology (An Autonomous Institution), Pin code:625701. prathibakarthy@gmail.com

[2]S. Nisha Rani, Assistant Professor, Department of ECE, Kamaraj College of Engineering and Technology (An Autonomous Institution), Pin code:625701. nisharani.84@gmail.com

[3]R. Rajprabu, Assistant professor, Department of ECE, Kamaraj College of Engineering and Technology Pin code:625701. rajprabucrp@gmail.com

Abstract

The integration of artificial intelligence (AI) with neural interfaces has revolutionized the field of prosthetic control, enabling enhanced user experience through more intuitive and responsive devices. This chapter explores the transformative role of AI in decoding neural signals, processing multi-modal data, and improving the real-time performance of prosthetic systems. By leveraging advanced machine learning techniques, including transfer learning and edge computing, prosthetics can now adapt to individual users' needs with minimal calibration and real-time responsiveness. Additionally, the fusion of neural signals with environmental data enhances context-aware prosthetic control, further bridging the gap between user intention and device execution. Despite the immense potential, challenges such as data synchronization, sensor fusion, and the limitations of existing neural decoding algorithms remain. This chapter also addresses the need for continuous research in these areas to achieve more seamless integration and user-centric outcomes. The discussed advancements and strategies have significant implications for the future of AI-driven prosthetics, offering insights into the next frontier of assistive technology.

Keywords: Artificial Intelligence, Neural Interfaces, Prosthetic Control, Real-time Processing, Transfer Learning, Multi-modal Data Fusion.

Introduction

The integration of artificial intelligence (AI) with neural interfaces has marked a significant shift in the development of prosthetic technologies, offering a new era of advanced assistive devices [1]. Historically, prosthetics were mechanical, relying on basic control systems and passive feedback from the user [2]. These devices often lacked the precision and adaptability required for seamless integration into everyday life [3]. The advent of neural interfaces, particularly brain-computer interfaces (BCIs) and peripheral nerve sensors, has enabled a more direct and effective method of controlling prosthetic limbs [4]. AI has further revolutionized this field by enabling the real-time decoding of neural signals, translating user intentions into precise, coordinated movements of prosthetic devices [5]. By leveraging deep learning models and neural networks, AI can interpret complex neural data and improve the interaction between the user and the prosthetic, creating a more intuitive and responsive experience [6].

AI-powered prosthetics operate by capturing neural activity, which serves as a proxy for the user's intended movements [7]. These signals are then processed using sophisticated machine learning algorithms, which interpret the data and generate control commands that drive the prosthetic device [8]. The challenge lies in decoding these signals accurately, as neural signals are noisy, dynamic, and vary significantly between users [9]. Traditional prosthetic systems often require significant calibration to account for individual differences in neural patterns[10]. AI techniques such as transfer learning and deep learning models can learn to adapt to these variations with minimal intervention, improving the system's accuracy and responsiveness [11]. These techniques enable prosthetics to be more flexible, offering a tailored experience for each user, and reducing the need for frequent recalibration [12].

A crucial aspect of modern prosthetics is the ability to respond to the user's environment in real time [13]. For prosthetic devices to function effectively, they must adapt not only to the user's neural signals but also to the dynamic environment in which they operate [14]. Environmental factors such as obstacles, terrain, and objects in the surroundings must be considered when controlling prosthetics [15]. Multi-modal data fusion plays a significant role in addressing this challenge, combining neural data with real-time sensory inputs from environmental sensors [16]. For instance, cameras, depth sensors, or inertial measurement units (IMUs) provide valuable contextual information that can be used to adjust the movement or behavior of the prosthetic device [17]. The fusion of these data types allows for more intelligent decision-making, enabling prosthetic limbs to respond appropriately to environmental cues, thus improving the user's experience and enhancing device functionality [18].