A Low-Cost Intelligent 3D-Printed Prosthetic Arm Controlled Exclusively by EEG Signals Using Adaptive Machine Learning

Trisha Paul
Electronics & Communication Engineering Department
Jadavpur University
Kolkata 700032, India
trishapaul612@gmail.com

Swati Chowdhuri
Electronics and Electrical Engineering Department
Institute of Engineering & Management, University of Engineering & Management
Kolkata 700091, India
swati.chowdhuri.iemcal@gmail.com

Joydip Roy
Mechanical Engineering Department
Swami Vivekananda University
Telinipara, Kolkata, India
joydiptutanroy@gmail.com

Sabyasachi Saha
Electronics & Communication Engineering Department
Swami Vivekananda University
Telinipara, Kolkata, India
sabya.saha@protonmail.com

Sougata Adhikari
Electronics & Communication Engineering Department
Swami Vivekananda University
Telinipara, Kolkata, India
sougataadhikarij7@gmail.com

Sheli Sinha Chaudhuri
Electronics and Telecommunication Engineering Department
Jadavpur University
Kolkata 700032, India
shelisinhachaudhuri@gmail.com

2026 9th International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech) | 979-8-3315-6339-4/26/$31.00 ©2026 IEEE | DOI: 10.1109/IEMENTECH202669403.2026.11434304

***Abstract*— Electroencephalography (EEG)-based control has emerged as a promising solution for intuitive and non-invasive control of assistive robotic devices, particularly for individuals with severe limb loss or neuromuscular impairments where muscle signals are unavailable. This paper presents the design and development of a low-cost, lightweight 3D-printed prosthetic arm controlled exclusively by EEG signals. The proposed system decodes user movement intention directly from brain activity using signal processing, sensor fusion, and adaptive machine learning techniques. EEG signals are acquired through a non-invasive multi-channel headset, conditioned to suppress artifacts, and transformed into meaningful features representing motor imagery and movement intention. To improve reliability and reduce noise sensitivity inherent in EEG signals, multiple signal fusion and filtering techniques—including averaging, weighted averaging, Principal Component Analysis (PCA), and Kalman filtering—are investigated. Experimental results demonstrate that Kalman filter-based fusion significantly enhances signal stability and control accuracy in real-time prosthetic operation. The prosthetic arm employs a modular 3D-printed mechanical structure with servo-driven actuation, ensuring affordability and customization. Additionally, a future bidirectional feedback framework based on deep learning is proposed to enhance user adaptation and sensory perception. This work contributes toward accessible, intelligent, and fully brain-controlled prosthetic systems for medical rehabilitation and assistive healthcare.**

Keywords*— *EEG-based prosthetic arm, rehabilitation robotics, EEG based Sensor fusion.

I. Introduction

Loss of an upper limb due to trauma, congenital disorders [1], neurological diseases, or amputation significantly impacts an individual's independence and quality of life. Prosthetic arms aim to restore lost functionality; however, many conventional prosthetic systems rely on mechanical switches [2] or muscle-based control, which may not be feasible for users with high-level amputations or neuromuscular impairments. As a result, there is a growing demand for prosthetic devices that can be controlled directly through neural activity. [3]

Electroencephalography (EEG) has gained considerable attention as a non-invasive brain–machine interface (BMI) [4] modality due to its portability, low cost, and high temporal resolution. EEG-based prosthetic control enables users to operate assistive devices through motor imagery or movement intention without relying on residual muscle activity.[5],[6] Despite these advantages, EEG signals suffer from low signal-to-noise ratio, susceptibility to artifacts, and inter-subject variability, which pose challenges for reliable real-time control. [7]

Recent research has demonstrated that advanced signal processing and machine learning techniques can significantly improve EEG-based control performance. In addition, sensor fusion and adaptive filtering methods have been shown to enhance robustness against noise and environmental interference. Meanwhile, advancements in additive manufacturing have enabled the development of lightweight and cost-effective prosthetic structures through 3D printing. [8],[9]

This research proposes a fully EEG-controlled prosthetic arm that integrates intelligent signal processing, adaptive machine learning, and a modular 3D-printed mechanical design. The objectives of this study are:

1) To develop a low-cost prosthetic arm controlled exclusively by EEG signals.
2) To evaluate sensor fusion and filtering techniques for EEG noise reduction.
3) To implement machine learning-based intention decoding.
4) To propose a scalable framework for future bidirectional brain-controlled prosthetics.

Ease of Use