A Novel Brain-Driven Forearm Exoskeleton With Adaptive Neuroregulation-Based Feedback for Subacute and Chronic Stroke Rehabilitation

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Exoskeleton robots have proven effective in rehabilitating patients with upper limb neuromuscular impairments. However, existing designs often lack essential components such as brain-driven recovery mechanisms, active participation for motor learning, real-time sensory feedback, forearm-specific support, and robust safety features. This project addresses these gaps by designing a brain interface to detect brain intention and detect Alpha Wave Suppression—a neural marker of mental engagement—to enhance brain involvement in rehabilitation, and a forearm exoskeleton with advanced safety measures with real-time feedback. This multimodal rehabilitation system includes an electroencephalography (EEG)-based brain control system, a 5-degree-of-freedom (DOF) forearm exoskeleton, and real-time vibration haptic feedback into a closed-loop rehabilitation framework. The whole design features a lightweight (<1.5kg), adjustable exoskeleton and an ultra-low-cost (<$100) EEG system which enhance its accessibility. The performance evaluation demonstrates its high accuracy rate (>95%) in EEG data acquisition, >92% accuracy in steady-state visual evoked potential (SSVEP) data classification and 100% accuracy in Alpha Wave Suppression recognition using BrainFormer, a customized machine learning model. These results highlight the system's ability to enable brain-controlled rehabilitation with adaptive neuroregulation, real-time sensory feedback, and personalized movement assistance. By overcoming the limitations of conventional exoskeletons, this innovation provides an affordable, effective, and accessible solution for improving motor recovery and promoting neuroplasticity in subacute and chronic stroke patients.

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