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BCIs in Upper-Limb Prosthetics: A Noteworthy Innovation In Combatting Paralysis

Abstract

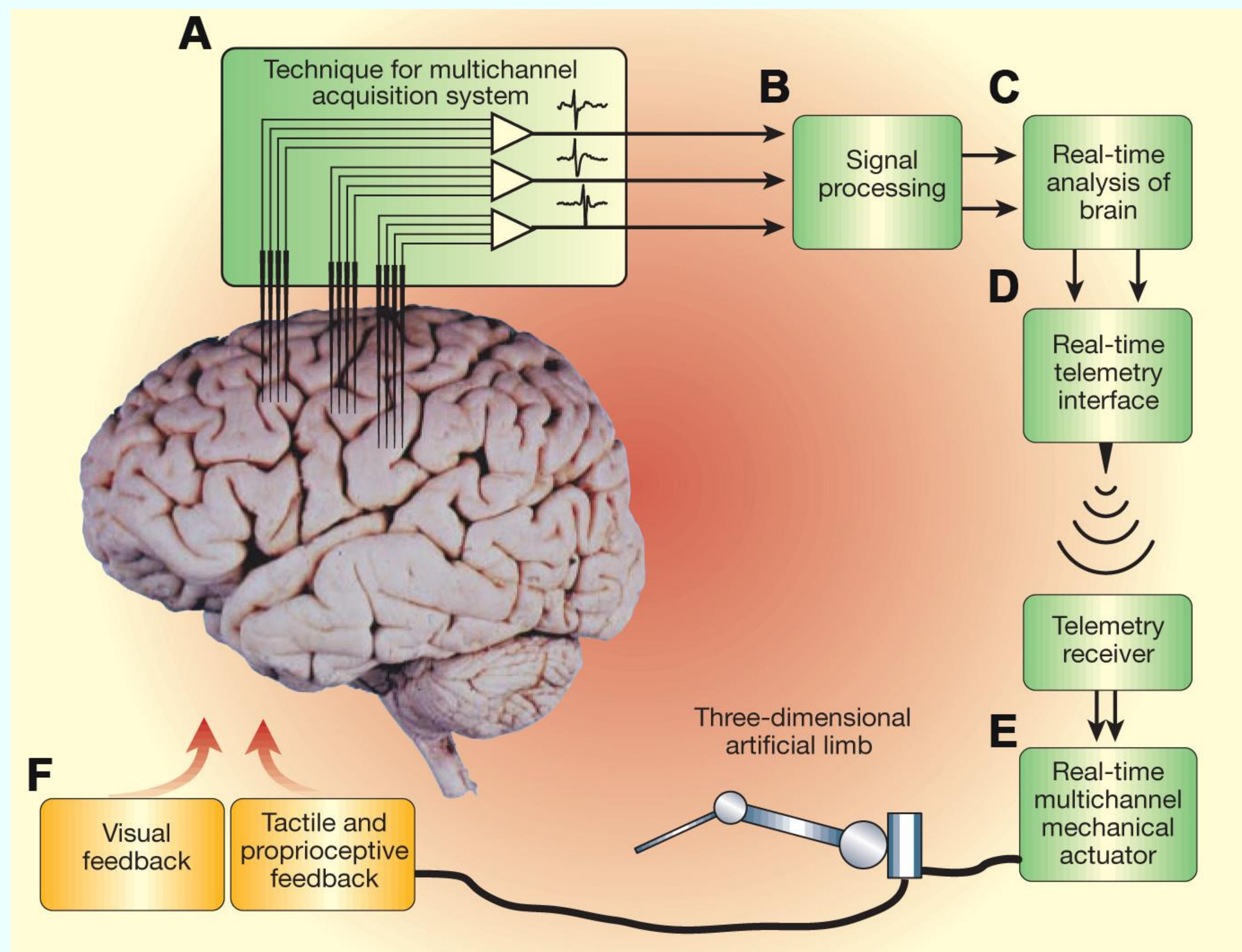
Millions are paralyzed or experience paralysis-related symptoms from strokes. Causes range from diseases and disorders to tragic accidents. Historically, doctors and scientists have attempted to combat paralysis by relying on traditional physiotherapy. Recently, researchers and professionals have seen success in building brain-computer interfaces (BCIs) to facilitate human-computer interaction (HCI). BCIs directly receive signals from brain activity and use this input to control computers. Developments in BCIs have transformed prostheses into an emerging solution for those affected by paralysis. Motor and sensorimotor BCIs confront paralysis through prostheses, enabling sufferers to partially or fully regain their self-sufficiency. Paralysis exists in many forms, each of which must be considered separately. BCIs have a short yet pertinent history for prosthetic technology, and their technical characteristics need to be examined in the context of biomedical application. Contemporary technological and medical development have led to BCI implementations like shared control with autonomous robotics. Nonetheless, potential roadblocks to real-world use remain and serious safety concerns must be addressed. Despite the novelty of the technology, the future for BCIs in prosthetics looks promising.

Sustainability Concerns

- Biocompatibility risk in introducing foreign material
- Hemorrhage and infection risk during surgeries
- Corrosion of electrodes over time, losing accuracy
- Signal quality can lessen over time from tissue encapsulation of electrodes or if electrodes become biochemically isolated due to inhibited axonal growth or the pulling away of neurons
- Rapid technological development can lead to obsolescence of implanted BCIs
- Balance between quality of life and potential future developments differs for paralysis victims

BCI Basics

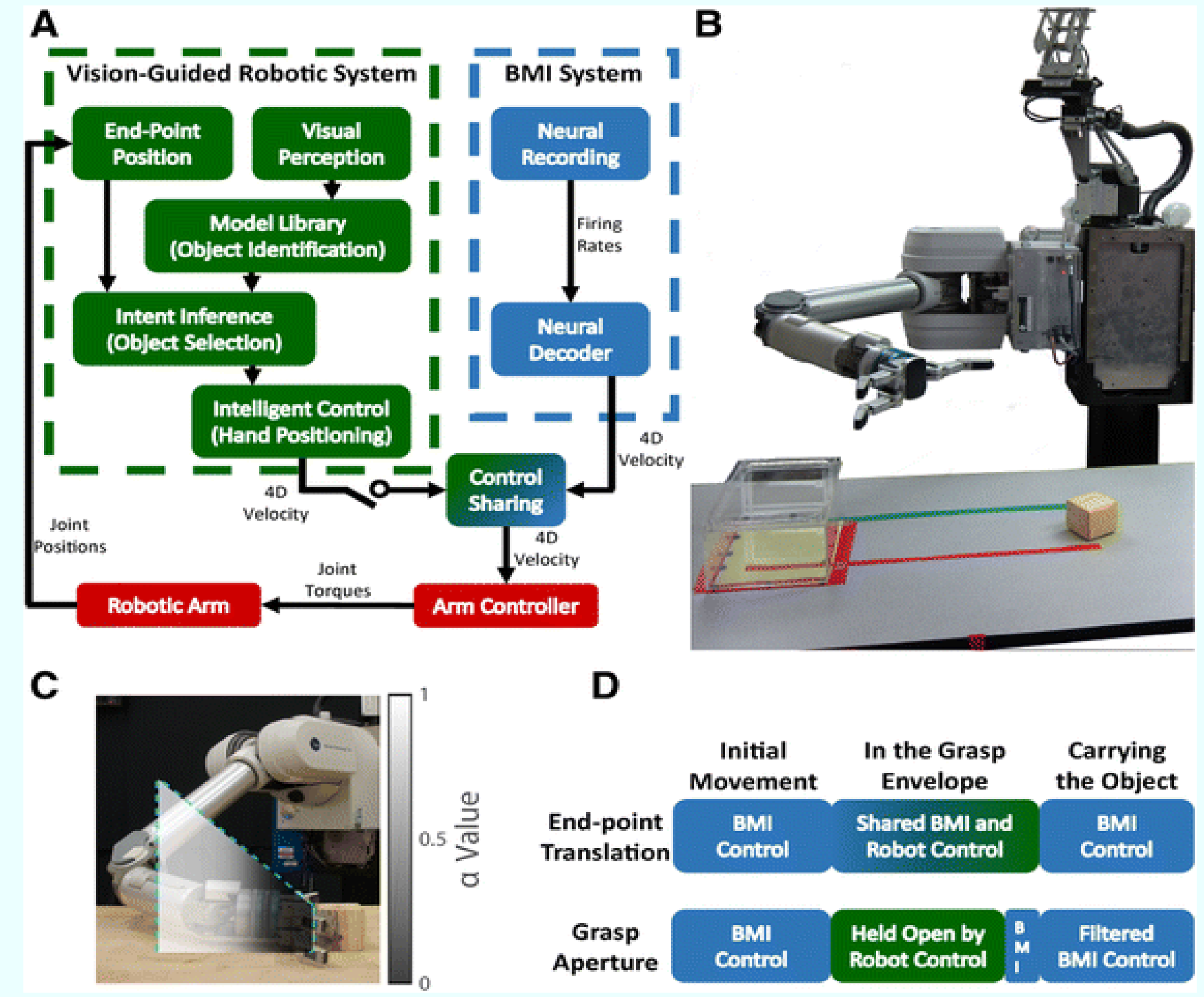
- Sensors that monitor neurological processes and translate input to computers for action
- Users explicitly manipulate their brain activity, overcoming the damaged pathway issue
- A mid-1990s flexible multi-electrode design led to subsequent explosive development
- Possibility of seamless brain interfacing has attracted federal and commercial attention
- Composed of electrodes for transmission, data processing, and power supply
- Invasive and non-invasive as well as wired and wireless options exist



Neuroprostheses

- Brain signals from multiple cortical areas are processed by a multichannel acquisition system
- BCI analyzes input and sends data to the upper-limb prosthetic
- Prosthetic performs the intended movements of the user
- Visual and tactile feedback is provided to the brain

Type of BCI	Description
EEG: Electroencephalogram (Non-invasive)	• Electrodes attached to the scalp • Monitors electrical activity in the brain • Decoding accuracy improves when more EEG channels are added
MEG: Magnetoencephalography-Based (Non-invasive)	• Uses brain magnetic fields as input • Sensitive magnetometers detect electric currents from cortical neurons
fNIRS: Functional Near-Infrared Spectroscopy (Non-Invasive)	• Measures the cortical metabolic activity with spatial and temporal resolution • Increases in oxyhemoglobin and decreases in deoxyhemoglobin provide neurofeedback input
ECoG: Electrocorticography (Invasive)	• Electrodes located on the cortical surface measure brain activity • High-frequency rhythm signals carry large amounts of information that can perform many cognitive operations, including motor movements



Shared Control Robotics

- Robotic system identifies objects, defines stable grasping positions, and stabilizes hand during grasping
- Autonomous assistance (machine control from AI) while giving the user the impression of self-autonomy
- [A] Blue BCI boxes intake and transmit data always; Green boxes apply when system is turned on, offering shared control through an integrated inferencing loop
- [B] Study subject attempts to place cube into box
- [C] Cross-section of the grasping envelope with gradient of shared control: low α value means more robotic assistance in executing motor movement
- [D] Translation of the arm mainly depends on BCI system unless near block; grasping aperture is controlled by the robotic system once in the envelope

Looking Forward

- Field of BCIs in prosthetics is in its infancy
- New developments in shared control and computer autonomy make them a potentiality
- Obstacles exist, but research efforts are strong