A Review of the Physical Principles of Brain–Computer Interfaces and their Contemporary Applications for Motor Rehabilitation

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Abstract

- Over the past few decades, **Brain Computer Interfaces** (BCIs) have emerged as a powerful and practical tool for clinical neuroscience. This is because it allows direct communication between neural activity and the physical world through the manipulation of neural activity, bypassing the biological need for the connection between the peripheral nervous system and central nervous system to create a motor output.
- The implications of BCI are widespread; we can see the effects clinically, such as allowing paralyzed patients to regain the faculty of movement through either using BCI devices as an extension or rehabilitating the CNS-PNS connection
- BCI applications are a compelling tool for patients with motor impairments, surpassing traditional devices and physical therapies for reclaiming of motor ability
- This poster focuses on the specific application of EEG-based BCIs on rehabilitation of motor skills, highlighting the technicalities, current research, and future applications that it implies.

The Biology of BCI

- BCIs heavily rely on the functional topography of our brains: to convert motor intent to real-world actions, we must first understand the brain regions involved and be able to interpret what intent their specific neural activities are purposed for [1].
- Most BCI approaches are centered on the Primary Cortex (i.e. motor, somatosensory, visual cortex). In particular, the motor cortex has relevance due to its control of movement and thus, interaction with the physical world and communication of desires. We will examine a case of the movement of fingers and its corresponding area of activation in the primary motor and somatosensory cortex [1].

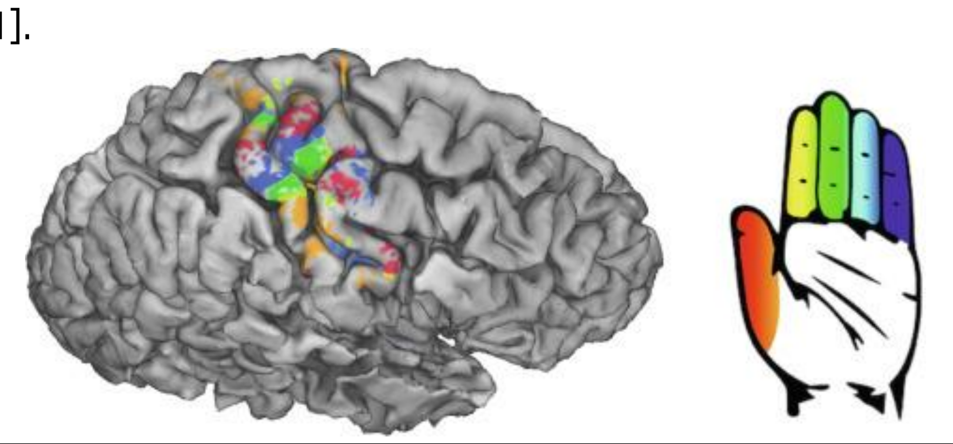


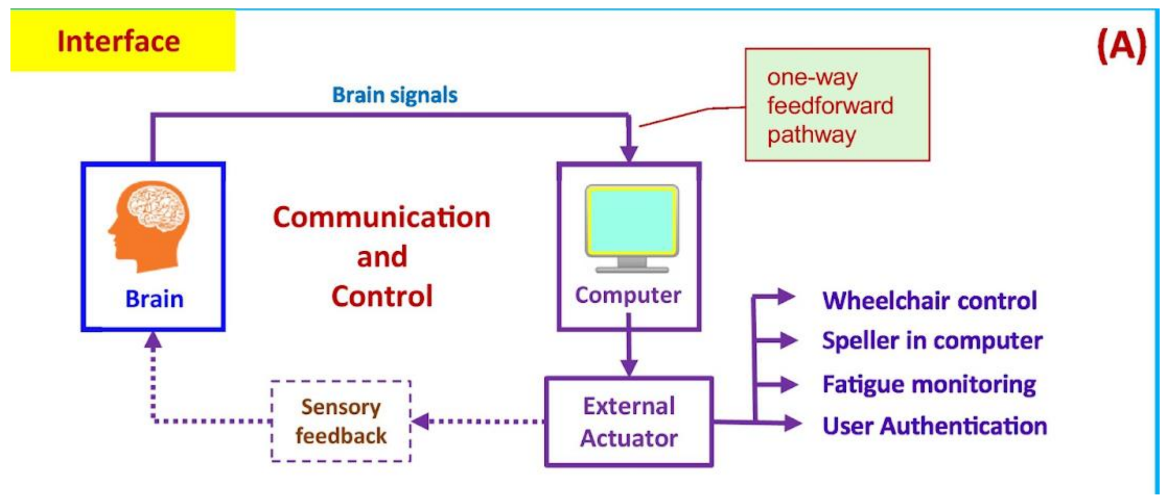
Diagram captured using population receptive field method, showing somatotopic organization of fingers, with colors on hand representing control areas in brain. Research done by Schellekens et al. to create detailed somatotopic organization [1]

The Biology of BCI (cont.)

- Even detection of finger activity in the brain is complex, with the activity of an individual finger often showing significant overlap in the activated brain areas detected across other fingers. These signals have been applied to communication (American Sign Language), where research has shown that ASL representing the alphabet letters could be decoded with 63% accuracy using data from sensorimotor cortex 7T fMRI. In the same study, above-elbow amputees attempted the gestures and decoding performance yielded a success rate of 64%, demonstrating the feasibility of using BCIs for communication. In actuality, the exactness of the understood relationship between the sensorimotor cortex and its kinetics and kinematics are virtually unknown, leaving room for more improvement and precision in decoding models. [1]
- The somatotopy of the primary cortex extends to other corporeal areas, and can even extend to external devices (i.e., wheelchairs and computer mouse) that serve as extensions of the body.

The Feedback Loop

- One-way feedforward pathways accurately describe the mechanism of classical BCIs. The technicalities of BCIs are relatively straightforward: brain signals are measured by technologies such as EEGs, which are then forwarded to a computational device to decode the user's intention by pattern recognition, or comparing the amplified signals to actual signals recorded when the desired action is done. This finally results in an output, whether that be controlling a wheelchair or spelling on a computer [2].

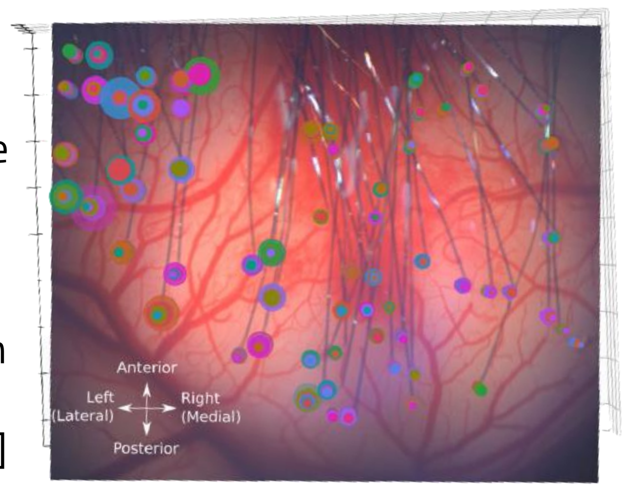


Classical BCI consists of a one-way feedforward pathway wherein control and communication are emphasized applications [2]

- It is important to note that **Sensory Feedback** is essential for the effective operation of a BCI, as it provides the ability to control the accuracy of deciphering brain activity signals by allowing the user to interpret the effects of their intended actions [3]

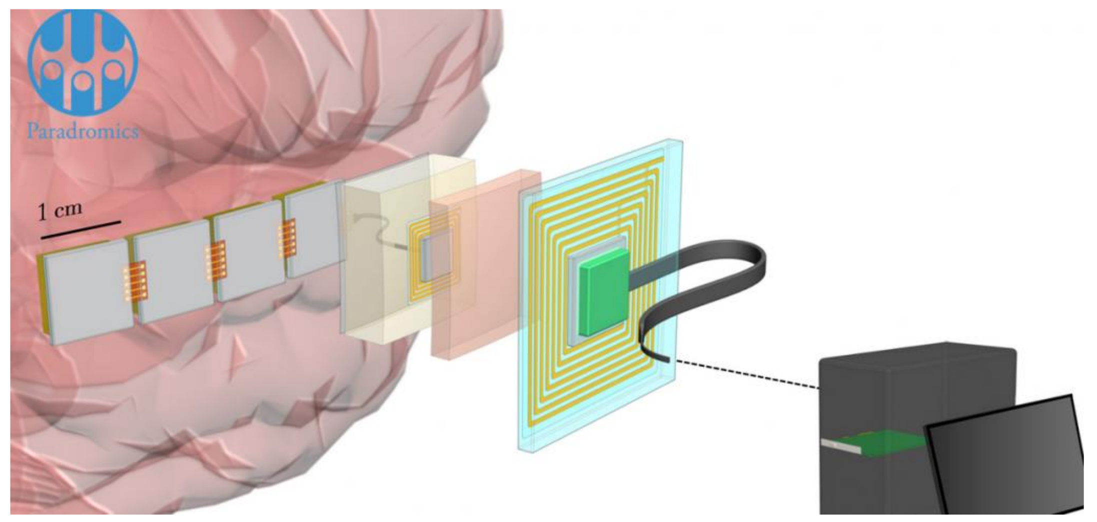
Current Research Projects

- **Neuralink** is a project that aims to develop an implanted BCI that would enable people suffering from paralysis to use neural activity to operate mobile devices/computers. [4]
  - Recently, Neuralink revealed they were able to enable a macaque monkey to move a cursor on a computer screen with only its neural activity and an implanted neural recording/data transmission device (N1 Link) [4]
- The Neuralink model contains 96 flexible polymer threads that are inserted into the brain for as many as 3072 electrodes, allowing greater precision in brain signal detection versus noninvasive methods [5]



Each circle represents one electrode, with its size representing modulation with movement observed in neural activity recorded by electrode. Image was taken during surgery, showing where threads penetrate the cortical surface. [4]

- The **Neural Input-Output Bus** (NIOB) is a project by Paradomics that aims for restorative therapy (for nervous system or brain diseases) by means of converting neural activity into computer signals (and vice versa). [6]
  - The model consists of specialized implantable cortical modules (microwires) that penetrate the brain's cortex where signal fidelity is the highest. [6]
  - The NIOB is unique in that it can connect to 1 million neurons, which is essential for a seamless, high-speed data stream between the human brain and digital devices [7]

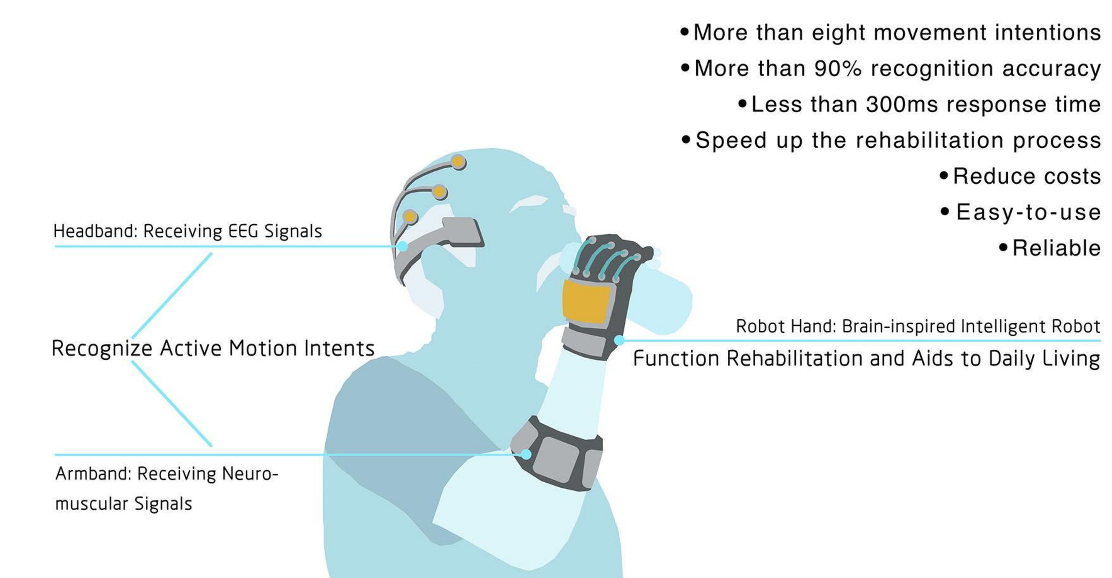


A NIOB system; Larger, implanted chips connected to bundles of microwires to interface with 1 million neurons for the fastest data transmission in its field [7].

- Both projects are similar in their models (implantable devices versus noninvasive) and applications for future clinical research, especially for patients with motor disabilities.

Current Research Projects (cont.)

- The **NCyborg Project** (neural cyborg) is a stroke rehabilitation design based on the coordination of a robot limb and an Electroencephalogram-based Headband to recognize motor intent through pattern recognition [8]
  - Stroke rehabilitation relies on neuroplasticity, motion function reorganization of brain tissue, and rehabilitation of the blood circulatory system and the muscular system, all of which are accomplished through encouraging the usage of muscles involved in movement intent [8]



A model of the stroke rehabilitation robot; the EEG signals would transfer the motor intent to the armband, which would receive and decode the signals for the robot hand to carry out [8]

Conclusion

- Brain Computer Interfaces still have much improvement to make in technical aspects such as measurement and pattern recognition of neural activity, both of which still show some significant inaccuracies
  - Even then, the human brain is complex and not completely understood, but BCI research promises to yield greater understanding, especially on the relationship between limb dynamics and cortical recordings
- Sensory feedback is essential for the effective usage of classical BCIs, which use one-way feedforward systems
- Extra-cranial BCI systems are simple and relatively inexpensive, but many researchers are turning towards intra-cranial approaches for better signal detection
- Current research projects on BCIs are promising and innovative models to rehabilitate motor skills in people with impaired motor skills

References