A digital bridge to restore hand and arm functions after paralysis

Problem: Every year, approximately 500,000 people suffer a spinal cord injury (SCI), which imposes profound human, societal, and economic costs. The most severe SCIs, particularly those involving the cervical spine, can lead to complete paralysis of the hands, leaving patients unable to perform basic daily tasks for the rest of their lives, with little to no prospects for meaningful treatment or recovery.

Current approaches: The current standard of care emphasizes physical rehabilitation, but this offers limited benefits, especially for those with severe cervical SCI. Emerging approaches involving electrical stimulation aim to restore hand and arm functions. Several methods have shown promise in clinical translation, including:

- **Epidural Electrical Stimulation (EES):** Electrodes are placed on the spinal cord's epidural surface to stimulate motor functions[1].
- **Non-Invasive Electrical Stimulation:** External stimulation devices are used to activate neural pathways without surgery[2].
- **Direct Peripheral Nerve Stimulation:** Electrodes are applied directly to peripheral nerves to facilitate muscle activation[3].

These interventions have demonstrated functional improvements in people with cervical SCI, yet they do not fully restore natural motor control.

Vision: The ultimate goal is to enable paralyzed patients to regain control of their arms and hands naturally, using the power of their thoughts, even in cases of severe or complete cervical SCI. Brain-Computer Interface (BCI) technologies offer a promising path to achieving this vision, and have been used to restore walking after paralysis[4, 5]. By detecting a patient's intention to move, BCIs can optimize the parameters for electrical stimulation, thereby enhancing both immediate functional recovery and the long-term process of neurological rehabilitation.
Some available BCI technologies, each with distinct advantages, limitations, and safety considerations are the following:

1. **Invasive BCIs:** Electrodes are implanted directly into[6] or onto[7] the cerebral cortex, offering high-resolution signals.
2. **Partially Invasive BCIs:** Electrodes are placed on the cortical surface (e.g., on the dura mater) to record electrocorticography (ECoG) signals[5].
3. **Non-Invasive BCIs:** Devices such as electroencephalography (EEG) are placed on the scalp, eliminating the need for surgery[8].
4. **Endovascular BCIs:** Electrodes are implanted through the bloodstream to reach an endovascular location near the cerebral cortex[9].

Assignment: You are young PIs who decide to collaborate to develop a digital bridge that bypasses the damaged spinal cord and restores hand and arm function in patients with cervical SCI. You have do develop your ideas inspired by the following roadmap.

1. **Develop an Optimal BCI Approach:** Identify and refine a BCI method best suited for detecting motor intentions for hand and arm movement restoration.
2. **Select and Design an Electrical Stimulation Method:** Choose an electrical stimulation approach that complements the selected BCI technology to maximize functional recovery.
3. **Create a Motor Intention Analysis System:** Design a system that accurately interprets motor intentions and dynamically adjusts electrical stimulation parameters in real-time.
4. **Integrate and Test the Closed-Loop System:** Assemble the full system to operate in a closed-loop configuration and conduct a pilot test with a 24-year-old female patient who has a cervical spinal cord injury at level C5 (classified as ASIA-B severity).

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