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A programmable closed-loop recording and stimulating wireless system for behaving small laboratory animals

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A portable 16-channels microcontroller-based wireless system for a bi-directional interaction with the central nervous system is presented in this work. The device is designed to be used with freely behaving small laboratory animals and allows recording of spontaneous and evoked neural activity wirelessly transmitted and stored on a personal computer. Biphasic current stimuli with programmable duration, frequency and amplitude may be triggered in real-time on the basis of the recorded neural activity as well as by the animal behavior within a specifically designed experimental setup. An intuitive graphical user interface was developed to configure and to monitor the whole system. The system was successfully tested through bench tests and in vivo measurements on behaving rats chronically implanted with multi-channels microwire arrays.

Significant progresses have been made during the past decade in developing engineered devices aimed at establishing a bidirectional interaction with the central or peripheral nervous system. The basic idea underlying devices designed for brain-machine interfaces (BMI) is to create artificial sensory or motor channels between the nervous system and the external world. By exchanging information, this can be used to control actuators as a robotic limb, a wheelchair or to drive the movement of a cursor on a computer screen. The main goal of these systems is to restore/recover functionalities in people with sensory or motor disabilities due to neurodegenerative diseases, strokes or spinal cord injury. These engineered devices have also been used as an experimental tool to explore the mechanisms involved in neural processes as memory, motor control, sensory information processing and synaptic plasticity^{1–4}. Motor BMIs are based on the idea of decoding the neural activity recorded directly from the motor areas of the cortex to control the movement of external artificial devices. Sensory BMIs have been developed to create artificial sensory channels by translating natural signals collected from the environment (e.g. sound, light, pressure) into proper artificial signals (e.g. intracortical micro stimulation patterns) to be fed directly into the brain. In this framework, cortical control of the movement of a prosthetic arm or of a cursor on a computer screen has been successfully demonstrated in studies performed on non-human primates and, in some cases, even on people suffering from high-level spinal cord injury⁵.

Regarding the possibility of directly stimulating the brain, deep brain stimulation (DBS) is a well-established procedure in the treatment of tremor associated with the Parkinson disease and multiple sclerosis^{6,7} while intracortical micro-stimulation (ICMS) is currently used in neuroprostheses to restore lost sensory functions in blind and hearing-impaired patients^{8,9}.

Mono-directional BMIs based on either neural recordings or stimulation continue to show great potential in improving the quality of life in patients suffering from a variety of neurological disorders, although a new generation of bi-directional systems aimed at combining neural signal recording and real-time processing with electrical stimulation for closed-loop applications is emerging^{10–13}. This is due to the evidence that a real-time feedback signal can improve the performances of a motor BMI in two ways: by allowing an online correction of errors and by activating a learning process in the areas involved in the loop¹⁴.

Most of the existing motor BMIs rely only on visual feedback to control the movements of external devices^{15,16}. However, the intrinsic delay of the visual system does not comply with the tight timing constraints typically required to control complex external systems. For this reason, researchers are exploring the possibility of providing information about the state of the controlled device through direct activation of the sensory area of

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