# TOWARDS A SPINAL NEUROPROSTHESIS:

# RESTORING LOCOMOTION AFTER SPINAL CORD INJURY

by

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# Abstract


The overall goal of this work is to develop the core framework for an implantable neuroprosthetic device that can restore locomotion after a severe spinal cord injury (SCI) causes paralysis. Our approach to this problem relies on a combination of the biological central pattern generator (CPG) for locomotion and an artificial silicon CPG. In particular, we propose that an artificial CPG can be used to generate on-line estimates of the motor output required to generate a desired gait, and that phasic electrical stimulation of spinal locomotor circuits can effectuate that output.

To validate our proposed approach, we first prove that phasic electrical stimulation can reliably modulate the output of the biological CPG for locomotion. Application of discrete current pulses to a single spinal segment is shown to affect multiple parameters of an ongoing locomotor pattern in excised portions of the chemically-activated lamprey spinal cord. For any given stimulus, the effects on frequency, duration, and symmetry of locomotor output are demonstrated to be functions of the phase at which stimulation is applied within the CPG cycle. Based on these responses, we show that it is possible to choose a desired motor pattern and use precisely-timed stimuli to conform the CPG's activity to the desired output.

The ability to generate specific motor output on-demand satisfies only one of the requirements of the proposed neuroprosthetic system. The other requirement is a method for determining what motor signals should be produced, and at what times. To provide an example of how this can be accomplished and apply it to an animal model of paralysis, we constructed a simple neural network based on the hindlimb CPG in cats that relies upon sensory inputs as well as intrinsic "ionic" currents to enforce a particular gait. Because we eventually intend to embed this network in an implantable device, we describe two different neuromorphic microchips that can be (re)programmed to implement arbitrary neural networks. A related neuromorphic system is then used to realize the hindlimb CPG network in hardware, and is subsequently employed to control locomotion in a paralyzed cat. This CPG chip receives sensory input describing the position and force produced by the cat's hind limbs in real-time, and generates action potentials that control the output of intramuscular stimulators connected to electrodes in the muscles of the hind limbs. Data are presented confirming the appropriate timing of swing and stance phases, a large range of motion, and significant loading of the hind limbs as the cat walks along a three-meter platform.

Taken as a whole, the aforementioned experiments provide proof-of-concept for all of the major components in our proposed neuroprosthetic device. Although we do not attempt to integrate the components in this work, we describe some of the issues foreseen in combining the various parts, as well as the steps required to migrate the model systems

ABSTRACT

to a human preparation.

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