Onboard Neural Processor on Vehicular BMI for Rat Toward Long-Term Operation

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Abstract. Brain-machine interfaces with implanted electrodes are promissing to observe and to modify activities in the brain. We have developed an invasive BMI "RatCar" in a form of a small vehicle to let a rat control the vehicle with cerebral motor signals while its body was held inside a pilot cabin. The system consists of an amplifier with band-pass filter, a signal processor computer, and motor-driven sustaining wheels. In this paper, a new vehicle containing all of those units installed inside is proposed. An initial operation test showed that the rat could stably board on the vehicle as the vehicle moved.

Keywords: Extracellular recording, Thin-film electrodes, Motor prosthesis, Motor cortex, Locomotion estimator, Rat

1. Introduction

Brain-machine interface with implanted electrodes are promising to provide methods to directly observe and possibly modify activities in the brain. They may control robotic body according to local neural activities more precisely conpared to non-invasive methods.

We have worked on a vehicular BMI system that we named "RatCar" [Fukayama et al., 2012] in these invasive motor-output BMI category. The device holds a rat inside its body and moves around as a whole, which provides the rat with natural sensory feedback caused by the movement. The ultimate goal is to let a rat to control the device recognizing that the device extended its naural body.

The RatCar is designed to drive wheels according to neural signals in the motor cortices as a rat intends to move its natural limbs. Currently, a rough estimation of the locomotion velocity has been achieved to move the vehicle in a forward direction.

The vehicle now includes an amplifier, a band-pass filter, an analog-to-digital converter unit, and a processor installed inside its body. We believe that this wireless and stand-alone setup enables an experiment for a longer period training a rat to leverage the vehicle as a locomotion method.

2. Methodology

2.1. Vehicle Body

The vehicle has been designed and fabricated as printed in Fig. 1. The vehicle body has a main deck made of aluminum box (*Takachi YM-180; W180xH40xD130*) sustained by 4 metal legs with a ball bearing at the each distal end. These bearings enable the vehicle to run smoothly on the ground. The deck contains an analog circuit for amplification and low-pass filtering of recorded signals inside the electromagnetically shielded body. Meanwhile, an analog-to-digital converter (ADC) unit (*USB-DUX Sigma*) and a handheld computer (*Brule Viliv S5*) are placed on the top.

The *USB-DUX Sigma* also provides output functions (analog and digital) to generate commands to control wheels attached to two rear legs of the vehicle. A motor driver IC (*Toshiba TA-7391P*) drives a DC motor connected to each wheel according to the command.

2.2. Locomotion Estimation

The primary motor cortical regions of a male Wistar rats have been chosen as a neural signal source. A set of neural electrodes (4 recording sites and 1 reference) made of parylene with gold conduction layer (Printed in a lower left part of the Fig. 1) were implanted in ambilateral tissues according to the cortical functional localization in stereotaxic coordinates.

The electrodes conduct extracellular potentials out of the brain and led them to the amplifier and low-pass filter (LPF) circuit which had a gain of 2 dB and high-cut frequency of 800 Hz. The amplified signals were then used as an input to the ADC unit sampling signals in 2 kHz under control of the handheld computer.

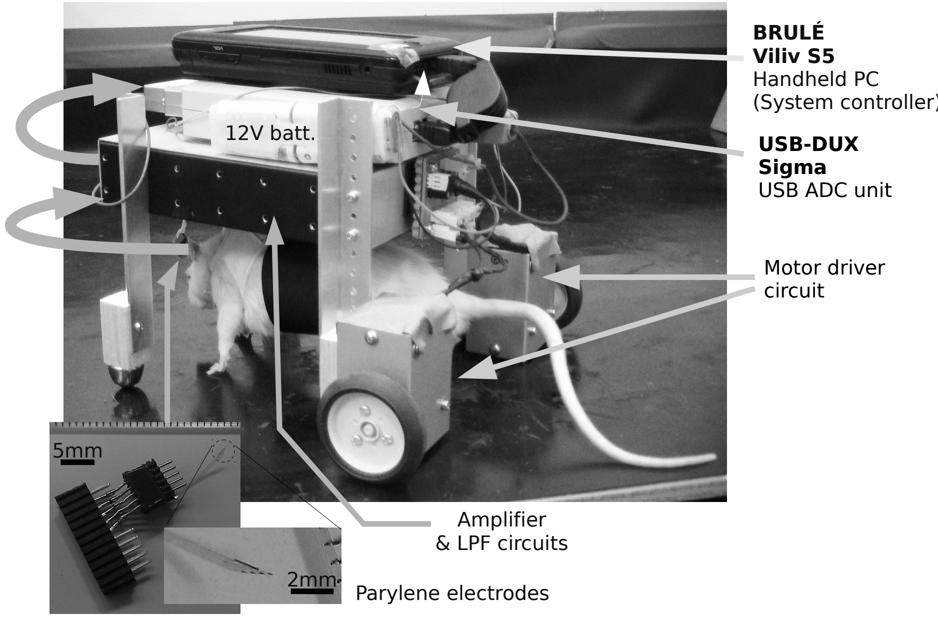

Figure 1: *RatCar vehicle holding a rat inside its "pilot cabin" with an on-board neural recorder, processor, and motor drivers.*

On the computer, self-made software on a Linux platform ran as follows; First, spiking rates of neural firings were extracted from the recorded signals. Then, they were applied to a linear model in a state-space representation where internal states described locomotion velocity and its differential (i.e., acceleration), and outputs vector described firing rates. The observation algorithm of Kalman filters provided an optimal solution for the internal states. Meanwhile, the correlations between those two variables were determined by preceding identification period.

2.3. Vehicle Control

According to the estimated locomotion velocity, the wheel rotation velocity was controlled to move the vehicle. As the vehicle moved forward, the rat was hanged under the vehicle floor with two "hook and loop" fastener. Its limbs were gently touching the ground so that the rat realize that its body was moving, but not able to kick the ground to drive the vehicle itself.

3. Operation Test and Future Directions

As the estimator controlled the vehicle, the limbs of the rat accordingly moved to follow the ground. However, its hindlimbs occasionally showed resistance against the movement. It was not clear whether the movement of the vehicle actually followed the intention of the rat, because the rat cannot complain about the precision of the control. The muscle forces in its limbs to resist against the movement may be used as error signals.

Although we have only tested the vehicle in a short time period up to 1 minute, stability to continue the experiments has been improved compared to former wired configurations that we had often run into nonessential troubles such as tangled cables. This setup enables an experiment to evaluate the estimation by letting a rat reach foods or waters in a longer period of time.

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