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Development of exoskeletal robotic limbs for a rat controlled by neural signals based on a vehicular neuro-robotic platform RatCar

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***Abstract*— A pair of exoskeletal limbs for a rat has been developed based on a vehicular Brain-Machine Interface "RatCar". The "RatCar" is a whole-body motor prosthesis system for a rat developed by the authors, estimating locomotion velocity according to neural signals pattern to move the rat body by the vehicle instead of its original limbs. In this paper, exoskeletal limbs have displaced the wheels for more natural modality of body control. The system was tested by applying peripheral nerve signals from a behaving rat.**

I. INTRODUCTION

Brain-machine interfaces (BMI) provide a new modality for communications and devices control. A number of applications are tested on human beings using non-invasive recordings from brains such as the electroencephalogram (EEG). On the other hand, direct extracellular potential recordings have been developed to extract more precise motor commands since Chapin et al [1] controlled a robotic arm using neural signals from the primary motor cortex of a rat.

The authors proposed a BMI system called "RatCar" in the form of a small vehicle. It is unique in that a neural signal source (i.e., a rat) is integrated inside the device (i.e., the vehicle body) and the whole components move around. The rat is therefore provided with direct visual and sensory feedback as the vehicle moves. This condition may promote the rat's brain to adapt to the vehicle system attached to its original body. Our goal is to let the vehicle collaborate with the brain to achieve a locomotion as the rat intended on behalf of its natural limbs. The system is designed to confirm fundamentals of neural recordings towards a future wheelchair application for human, and to observe functional changes in the brain during the connection with BMI from a neuroscientific view point.

A past study by the authors achieved a rough estimation of the locomotion according to neural signals in the motor cortices of rat brain[2]. Then, the vehicle holding a rat under the floor was proposed so that a rat was capable of exploring the ground either by its limbs pulling the vehicle, or by the vehicle under the control of neural signals (Fig. 1)[3].

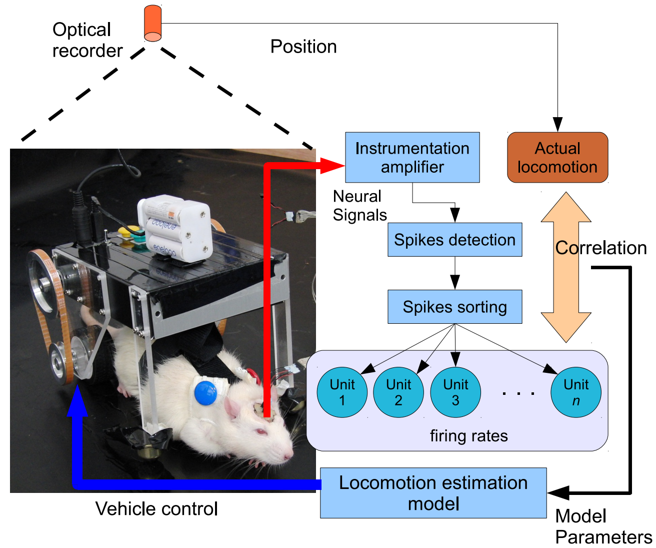

Fig. 1. "RatCar" system holding a rat under the vehicular body controlled by neural signals (Cited from Fukayama et al.[3]).

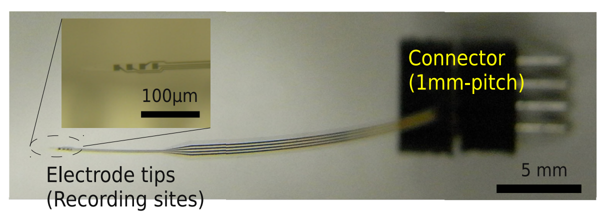

Fig. 2. An electrode bundle which has 4 recording sites on a tip and a connector on the other end. Cited from Fukayama et al. [3]

In this paper, a pair of robotic limbs displaced the wheels to move the vehicle in more intuitive way. The system was tested by applying sciatic nerve signals from a rat during locomotion.

II. RATCAR SYSTEM

A. Implants

RatCar system applies thin film electrodes made of parylene polymer on central nervous system (CNS) and peripheral nervous system (PNS) recording. They were inserted in primary motor cortices on both hemispheres of the brain for CNS recording. On other hand, the electrodes were pasted on the sciatic nerve bundles in the ambilateral limbs.

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All the experiments we performed followed guidelines given by the "Animal Experiments Committee of the University of Tokyo".

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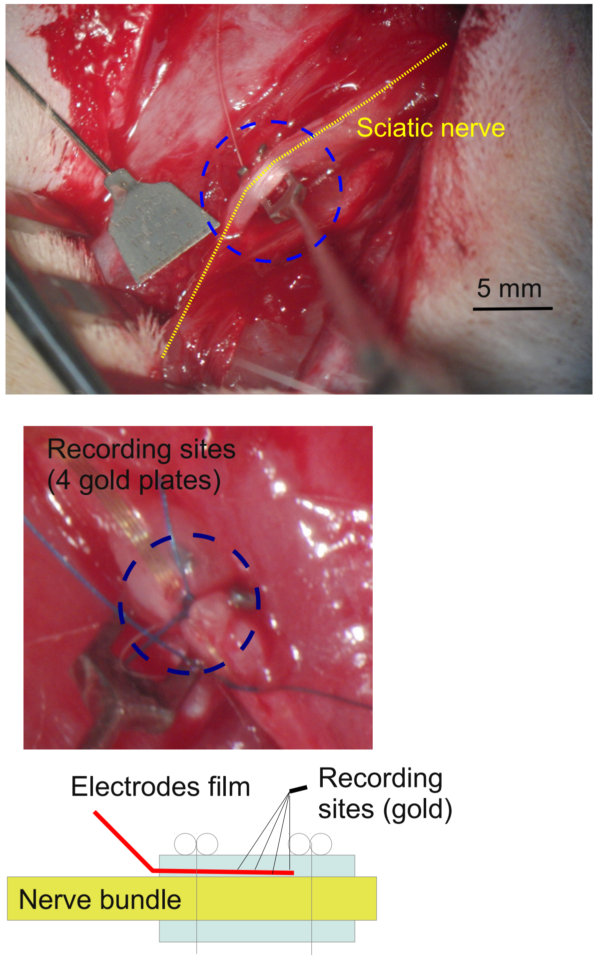

Fig. 3. (a) Sciatic nerve hooked with a metal equipment (rounded by the broken line circle), (b) Film electrodes pasted on the surface of the bundle.

The electrodes had been originally fabricated with MEMS technology to acquire extracellular multiunit activities (MUA). Each electrode had 4 gold recording sites on a thin soft layer made of parylene polymers (Fig. 2). A small connector (IC socket in 1 mm - pitch) was attached to connect the lines to an amplifier.

In this study, however, they were converted for PNS recording. Assempled active potentials from the sciatic nerve bundle was detected by pasting the gold recording sites on the surface (Fig. 3).

B. Signal Acquisition

Bio-potential amplifiers with active LPF at 5 kHz cutoff frequency (*Multichannel Systems FA-64*; gain=5,000) and linear passive HPF (to reduce motion artifacts) were applied to neural signals followed by a 25 kHz - sampling A/D converter (*National Instruments PCI-6254*) installed on a personal computer (Home-built; Core 2 Duo CPU; 2 GB memory).

Neural signals were derived by differentiating potentials between 3 recording sites and 1 reference site on each electrode. They were then amplified and filtered (Gain: 5,000, BPF: 500 - 5,000 Hz) by *Multichannel Systems PGA-64* or *FA-64* followed by an A/D converter (*National Instruments PCI-6071E*, 20 kSps for each channel) installed in a personal computer.

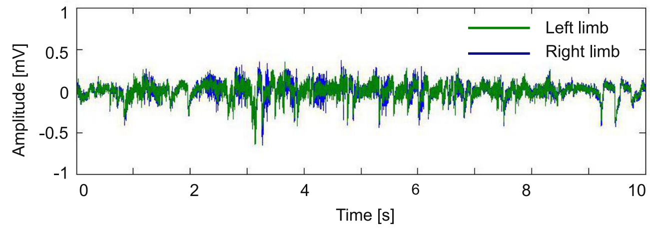

Fig. 5. Example of recorded signals from the sciatic nerve bundle. A green and blue line represents a signal from the left limb and the right limb, respectively. Neural signals was observed alternately in the limbs as the rat treaded around 2 - 6 s.

C. Vehicular Body

The vehicular body of RatCar had a high-floored structure hanging a rat under the floor. The rat was sustained under the vehicle floor by the jacket and belt so that its limbs gently touched the ground. According to an intention of a rat to move its body, the whole device was controlled.

III. Exoskeletal Limbs

A. Devices

Each robotic limb had one joint for azimuth rotation (not used for this study), and two joints for flexion and extension. The robotic limbs sustained the rear part of the vehicle to stand. Meanwhile, two free-moving wheels hold the front (Fig. 4).

B. Steps Detection

Signals from ambilateral sciatic nerve bundles (Fig. 5) triggered the movement of these joints. First, powers (variances) of the signals in every 100 ms bin were calculated. As a summation of the signal powers increased over a threshold (manually configured), we assumed that the rat had made a locomotion step. Then, the ipsilateral robotic limb on the same side of the sciatic nerves which generated a larger signal power compared to the contralateral nerves was controlled to extend its joints to kick the ground. Finally, the joints flexed to prepare for the next step as the signal power decreased below the threshold.

C. Calibration

An exercising wheel for a small animal (Fig.6) was converted into locomotion recorder for a rat. As a rat ran inside the wheel, the rotating velocity of the wheel and the peripheral neural signals (acquired via cables from the head) was recorded simultaneously. The speed of extending mechanical joints was calibrated to move the vehicle in a similar velocity as the rat ran.

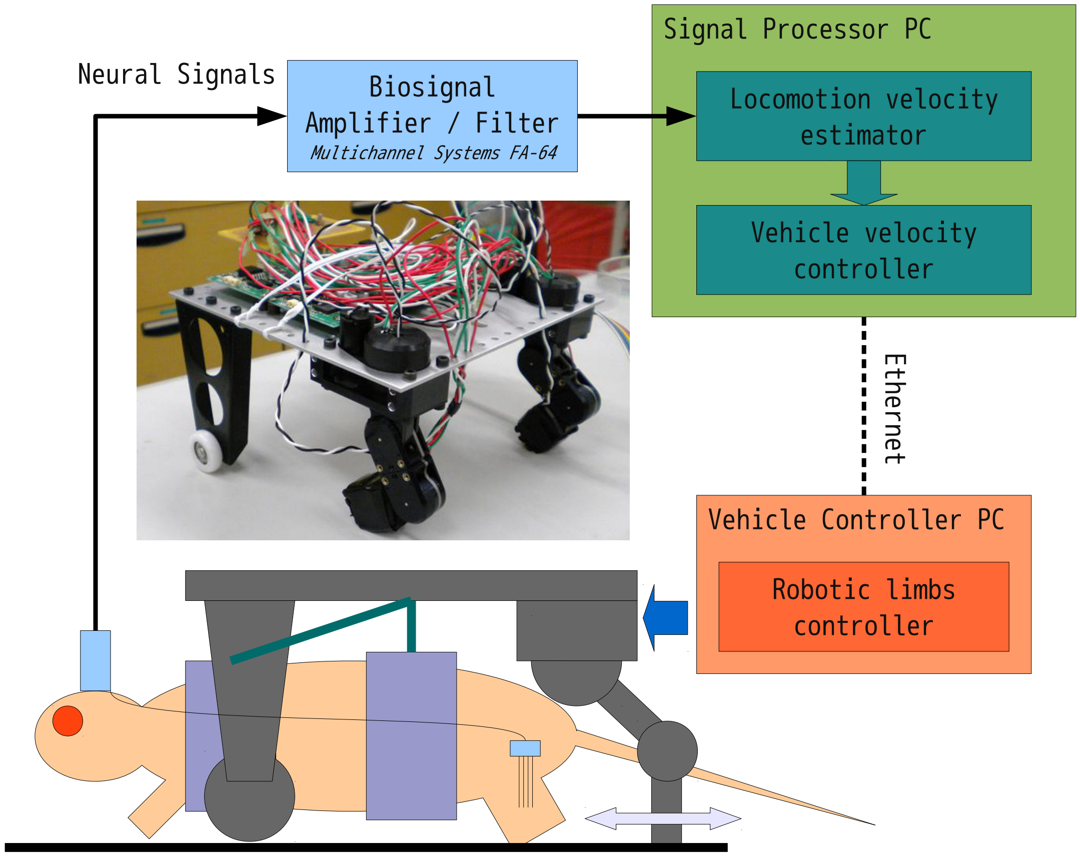

Fig. 4. RatCar in an exoskeletal structure. A rat is tied with the vehicle body with soft bands and leashes.

Fig. 6. A wheel to exercise a small animal that we converted into locomotion recorder for a rat.

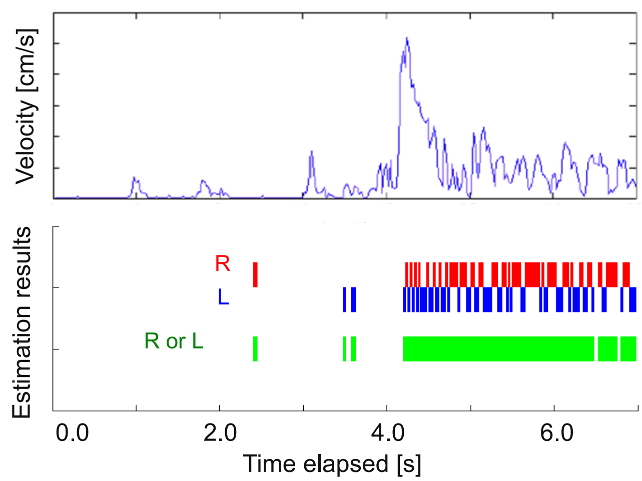

Fig. 7. Locomotion velocity of a rat inside the exercising wheel shown above, and estimated steps on the right (R) and left (L) limb and either limbs (R or L) shown below.

D. Operation Test

The system was tested by controlling the vehicle beside of a behaving rat inside the exercising wheel. A synchronous stepping pattern of the robotic limbs with the natural limbs of the rat was observed. Figure 7 shows the alternating steps by the method described above.

IV. Discussion and Conclusions

Compared to the neural control of rotating wheels with motor cortical signals from the motor cortex of the brain, a connection from peripheral nerve to robotic limbs were more intuitive and a simple algorithm could drive the vehicle.

However, the signal recorded from the sciatic nerve may have included activities which were not related to locomotion. They should be removed for a more reliable control.

In this paper, a pair of robotic limbs displaced the wheels to drive a vehicle which hold a rat under its floor. By applying sciatic nerve signals from a behaving rat, the vehicle was driven to step forward corresponding to the actual velocity of the rat.

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