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Neural Signal Sensing, Transmission and Functional Regeneration on Different Toads' Bodies

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***Abstract*—The presence of neural signals is the most important feature of animals' life. Monitoring, analysis and regeneration of neural signals are important for the rehabilitation of paralyzed patients. In this paper, the neural signal regeneration between the proximal and the distal end of an injured nerve is introduced. In the experiment a microelectronic module is used as a channel bridge. The regeneration of nerve signals is realized from one toad's sciatic nerve to another's. Corresponding neural signals and EMG were recorded and analyzed. It will be a reference to further study on the neural signals and the relationship between a neural signal and the muscle locomotion.**

I. Introduction

Damage on a central nervous system (CNS), especially on a spinal cord, will result in a serious aftermath. When the spinal cord of a patient is injured, the body below the injured segment will become flaccid paralysis and loss of sensation, because the spinal cord losses the control of senior central. The body temperature can't be maintained normally, the stool is retarded, the bladder cannot be emptied, and the blood pressure is declined. These spinal cord injured (SCI) patients can't take care of themselves. It will be a heavy burden for the society and the family. Therefore, it is significative to study the neural signal sensing, transmission and functional regeneration.

On the neural signal detection and regeneration, we have studied for many years since 2004 [1, 2]. Using rats as animal models, many experiments of neural signal regeneration have been carried out. A series of results have been obtained [3~6].

We can imagine that the functions of each parts of a body can be recovered when the spinal cord signal of a paraplegic can be successfully regenerated. Although it will take a long time to reach this goal, our experiments have given the possibility. As an intermediate goal, we supposed that nerve signals can be taken out from the spinal cord and directly transmitted to the controlled object by an electronic information system, so that a part of the functions of the controlled target can be regenerated The neural signals can be delivered through wired or wireless signal channels to the left or right sciatic nerve.

In order to verify our idea that the neural signal can be transmitted by an electronic information system, we should get neural signal as signal input of the electronic system. In our experiments, spinal toads, instead of rats, were used as animal models. The first reason is that in the experiment a spinal toad can be used without narcotism and the neural signal can be recorded conveniently. The second reason is that spinal toads' spinal cords can keep living for a long time even more than one day. It is another advantage for us to do exercise repeatly. For the sake of avoiding the conduction of the organism itself, or introduction of other interference, we have designed the nerve regeneration experiment on sciatic nerves of different spinal toads, i.e. the sciatic nerve signals of one toad were regenerated through the microelectronics neural-bridging system on the sciatic nerve of another toad.

The microelectronic system, the electrode, and the animal experiments are discussed in this paper.

II. Microelectronic Neural-Bridging System

The microelectronic neural-bridging system, including the neural signal acquisition sensors, pre-buffer network, instrument amplifiers, signal processing unit, output driver, nerve stimulator and so on. The schematic of microelectronic neural-bridging system is shown in Fig. 1

The working principle of microelectronic neural-bridging system is as following: The electrodes are used as sensors of neural signals. The microelectronic neural-bridging system captures the weak neural signals from the proximal nerve bundle (in this demonstration is the sciatic nerve of a spinal

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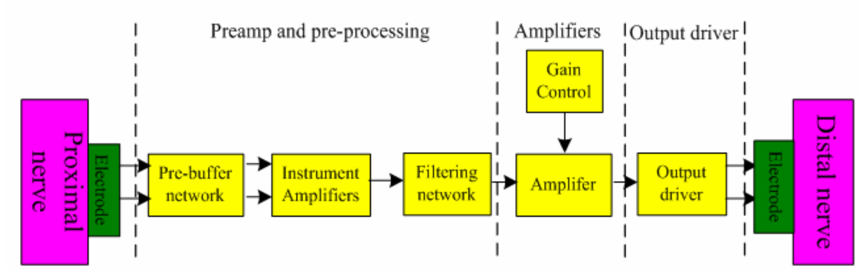


Fig. 1 The schematic of microelectronic neural-bridging system

toad). The neural signals are amplified by means of a high-gain and low-noise amplifier and then sent to the signal-processing unit. For the signal processing, an analog circuit, such as filter, was used in our present design. In fact, an analog-to-digital converter can be used after the signal unit, the signals are applied to the driving circuit. At the end, the signals are used to stimulate the distal nerve (in our demonstration it is the sciatic nerve of another spinal toad) and thereby the function regeneration under the control of nerve can be achieved.

The microelectronic neural-bridging system consists of two pairs of electrodes and one microelectronic module. The core part of the microelectronic module is a signal-processing unit, which consists of a detecting amplifier, a signal-processing unit, and an FES (functional electronic stimulation) driver. For present experiments, modules made both of discrete devices and of integrated circuits (IC) have been used. The module made of discrete devices including commercial operational amplifiers is shown in Fig. 2.

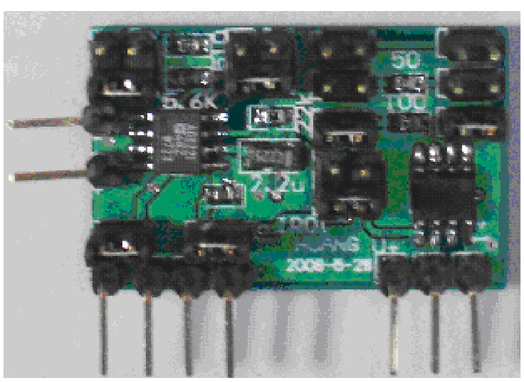


Fig. 2 The photograph of the microelectronic neural-bridging system made of discrete devices

The neural-bridging IC realized in a CMOS process consists of a low noise pre-amplifier, a current-mode instrumentation amplifier, an output buffer and a biasing circuit with a constant trans-conductance. The detailed description of the IC design will be given in an accompanied paper which is also submitted to EMBC2009 [7].

In the experiment, we have induced spinal nerve signals on toad by dripping a few drops of 1% sulfuric acid on the toes of the left foot of a spinal toad. As a result of conditioned reflex, the spinal toad shrank his leg. In order to ensure the electrode in good touch with the sciatic nerve of the toad, a hooked electrode was used as detecting electrode. In order that the sciatic nerve of the second toad could be stimulated in a similar mode, another hooked electrode was chosen to make good contact with the sciatic nerve, and functioned as an FES electrode.

In order to study the relationship between the neural signals and the muscle locomotion, the EMG signals on the both toads' legs were monitored when detecting the sciatic nerve signals. For EMG monitoring [8,9], acupuncture needles were used as electrodes.

III. Animal Experiments

When rats, rabbits, dogs and other high-class vertebrate are used as animal models, they should be anaesthetized firstly before the experiments of neural signal regeneration can be carried out. The anesthesia, however, will suppress the excitement of the nerve. On the other hand, the drastic action of the animal that comes to its senses makes the experiments difficult to be carried out. That means, there is a contradiction with high-class vertebrate as animal model of neural signal regeneration and function rebuilding. In our experiments, therefore, spinal toads (toads whose heads or the neck nerves are cut off) were used. There are two advantages: First, anesthesia is not required, nerve signals generation and dissemination will not be inhibited, and the generation of nerve signals by a functional electrical stimulation will not be inhibited; Second, as amphibians, toads can maintain biological activity for a long time without the control of the brain. Both of the advantages are helpful for the experiments of neural signal regeneration.

In early experiments of our neural signal regeneration, nerve signals were induced by a square-wave electrical stimulation. In these cases, there always exists a stimulus artifact owning to the conductive feature of the organism itself. In order to avoid the stimulus artifact, we have introduced a kind of chemical stimulation to induce nerve signals: dripping drops of 1% sulfuric acid on toes of the foot of a spinal toad.

The course of the entire experiment is showed in Fig.3. Two spinal toads whose brain had cut off were laid on a board and their bellies were fixed on. The skin of the right side of the thigh was cleaved and the sciatic nerve was isolated with threading standby. Three pairs of hooked electrodes were hitched on the sciatic nerves as shown in Fig. 3. Two pairs of acupuncture needle electrodes were inserted into the muscles of the left legs of two toads and used to record the EMG signals. The distance between the FES stimulating hooked electrode and the monitoring hooked electrode was about 2.5 cm. In order to reduce artifacts, a metal coil was circled between the hooked and the needle electrode on the legs of

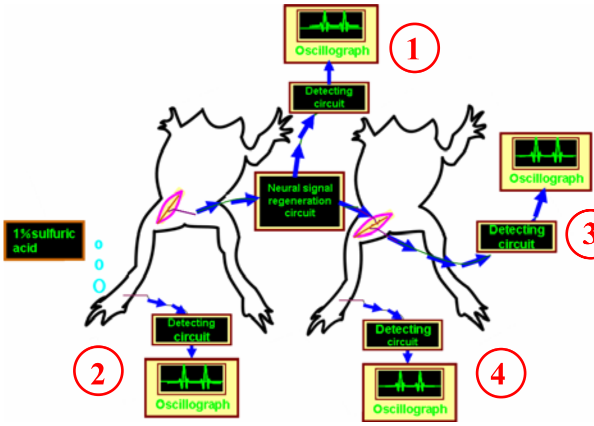
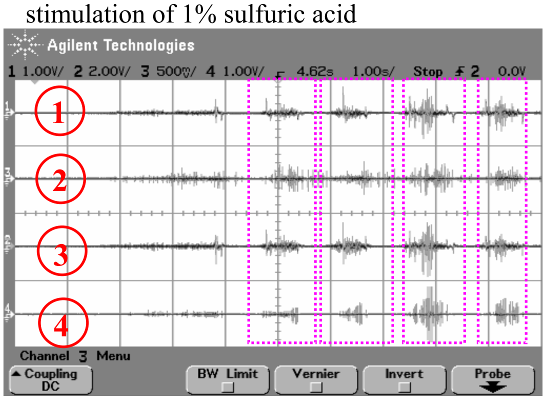
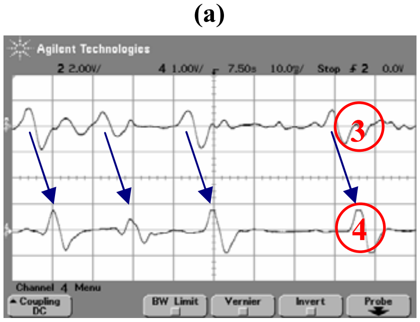


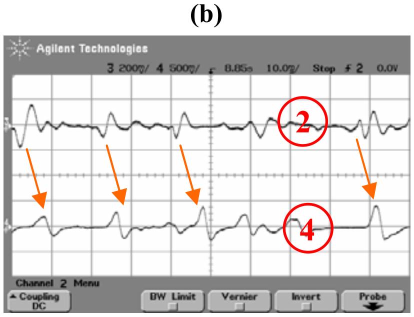
Fig. 3 The experiment schema of the signal regeneration between the sciatic nerves of 2 toads, under a stimulation of 1% sulfuric acid



(a)



(b)



(c)

Fig. 4 Sciatic nerve signals and EMG signals in a regeneration experiment

two toads and grounded. The spinal toads were actionless in absence of external stimulus. Dropping a few of drops of 1% sulfuric acid on to the toes on the left leg of the first toad, the first toad shrank its left leg, owing to the conditioned reflex. The sciatic nerve signal of the first spinal toad was transmitted to the sciatic nerve of the second spinal toad through the microelectronic neural-bridging system. We saw that the left leg of the second toad made similar action as the first toad. Both left sciatic nerve signals of two spinal toads were recorded. At the same time, the EMG signals of their left legs were also recorded. All four signals are shown in Fig. 4. And the whole process was recorded by a video camera. Then, the skin of the first toad's foot was watered as soon as possible and dried with gauze.

In Fig. 4(a), waveform ①-④ represents the signal detected on the sciatic nerve of the first toad, the EMG signal detected on the left leg of the first toad, the signal detected on the sciatic nerve of the second toad, the EMG signal detected on the left leg of the second toad, respectively.

Fig. 4 (b) and (c) are two segments which are intercepted from Fig. 4 (a) and interested for our discussion.

IV. Discussion

From Fig. 4 we can get following information:

1) In Fig. 4 (a), waveform ③ represents the regenerated sciatic nerve signal in the sciatic nerve of the second spinal toad. It is very similar to its source signal, namely waveform ① —the sciatic nerve signal of the first toad. That means that through the microelectronic neural channel bridge, the signal in the sciatic nerve of the first toad was successfully transmitted to the sciatic nerve of the second toad.
2) By observing the rough relationship between waveform ③ of the sciatic nerve signal and waveform ④ of EMG signal of the second toad in Fig. 4 (b), we can see that the EMG signal and its source signal, i.e. the sciatic nerve signal, has a definitive relationship. Each EMG impulse as the arrows pointed is caused by a corresponding impulse of the nerve signal.
3) In Fig. 4 (b) it is also proven that the nerve signal in the sciatic of the second toad is indeed a nerve signal rather than an artifact. If it was an artifact, it should include all small waves in its source signal. Only a neural system has the feature of the amplitude-discrimination, that is to say, only when the stimulation is higher than the threshold, a complete action potential signal will be generated.
4) The EMG burst shown in Fig. 4 (c) comes forth one after another. It is reasonable that the pulses in the EMG of the second spinal toad, waveform ④, comes slightly later than those of the first spinal toad, waveform ②. In addition, the 1st, 2nd, 3rd, and 5th pulses have obvious similarities. It is proven that there is a causality between the action and the signal.

V. Conclusion

We designed an experimental schema to verify the idea of the micro-electronic neural bridge. The regeneration of the signal in the sciatic nerve of one toad to another was demonstrated. At the same time, the neural signals and EMG signals were recorded and some relationships between the nerve signals and the EMG signals were revealed. This work builds up a basis of the study on the relationship between the action and the neural signal. Further more, we are going to study with rational quantitative methodology and hope to get more reasonable proofs.

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