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Motor Function Rebuilding of Limbs based on Communication Principle and Electronic System*

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***Abstract*—In this paper, we report our novel idea on the function rebuilding for hemiplegic limbs and the primary experiments. The main concept is to connect the control-lost nerves or neuromuscular junctions by using a multi-channel micro- electronic neural bridge (MENB), regenerate the nervous signal, and rebuild the motor functions of the related limb. Since the injured nervous system in stroke-related hemiplegia is located in the brain and difficult to be identified and operate on, we use another nervous system functioning as a new signal source to supply similar neural signals. In these cases, that means, two independent nervous systems are connected by a MENB. As preclinical experiments, we have made a series of tests on bodies of animals and healthy human. The principle, the system construction and the experimental results will be given.**

I. Introduction

According to the "Chinese Health Statistical Digest (2010)"[1] and the "Report On Cardiovascular Diseases In China (2010)"[2], there are 7 million patients suffering from stroke in China and among them about 4.5 million remain disabled to various degrees. Hemiplegia is the main type of the disability. Therefore it is of significant scientific meaning and clinic application value to study function rebuilding of hemiplegic limbs.

Since the focus inducing hemiplegia is located in the brain, i.e., in the central nervous system, the complete rehabilitation of such a disease is still extremely challenging. The substantial therapies should include two aspects: 1) the proliferation of neurons to replace the lost or dead ones by using medicament or biological methods and 2) different physical therapies to rehabilitate the functions that are potentially recoverable.

Early, it was believed that the regeneration of the neurons in the central nervous system of an adult mammalian is impossible [3]. In recent years, pioneer medical researchers have introduced olfactory ensheathing cell transplantation to remedy the sequelae of stroke [4]. The results according to two patients who were followed-up for 6 and 24 months indicated that the ADL (activities of daily living) scores were increased from 58.33±31.89 before operation to 64.17±33.23 after operation. In these cases, there is still an potential increase room of more than 30% on the ADL scores. That means other kinds of therapies may be still necessary for further treatment even if the cell transplantation becomes feasible.

In fact, many kinds of physical therapies are still in practice and in development for the motor function rehabilitation of paralysis including hemiplegia. Among physical therapies, the FES (functional electrical stimulation) is believed effective [5]. However, most FES systems of today are not effective enough, because of their following limitations. 1) the stimulating signals are artificially generated, 2) the system is open-looped, i.e., no feedback, and 3) less coordinated functions, such as grasping or standing up, can be formed. In results, about 10% of hemiplegia patients cannot recover the flection and extension function of the coxa and knee joint, about 40% cannot recover the flexion and extension function of the elbow and wrist joint, and about 80% cannot recover their hand functions. Hence the function rebuilding of hemiplegic limbs remains a challenging task in biomedical engineering.

In this paper, we will report our novel idea on the function rebuilding for hemiplegic limbs and the primary experiments. The idea originates from the patent applied by the two corresponding authors of this paper and Xiaosong Gu [6]. The main concept is to connect the interrupted nerve by a micro-electrical neural bridge (MENB) to regenerate the neural signals, and rebuild the motor function of the limb that is originally controlled by the interrupted nerve [7].

As shown in Fig. 1, the system in the top-down direction includes a detecting electrode array, a signal processor, a functional electrical stimulation (FES) driver, and an FES electrode array.

The problem with hemiplegia is that the injured nervous system is in the brain and the location is difficult to be recognized to operate on. Since there is no available signal source from the patient, we have extended the concept of the original MENB from bridging one interrupted nerve to bridging two independent nerves so that another nervous system supplies the similar neural signals and functions as a new signal source. In concrete, we make a connection between a paralyzed limb and a healthy limb, and use the motor signal

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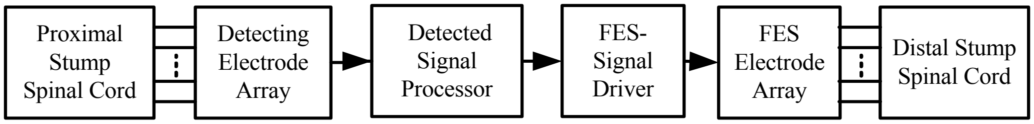

Fig. 1 Block diagram of the MENB system for bridging an injured spinal cord.

from a healthy limb to control the motor function of a paralyzed limb.

According to this concept we have successfully implemented the signal regeneration and function rebuilding between two far-separated nervous systems of toads [8].

In this paper, we will report the progress we have made further on this researching direction and give the new experimental results made in animal bodies and on skin of healthy human. The principle, the system construction and the experimental results will be given as follows.

II. Concept Development and System Construction

Originally, the concept of MENB was thought for the bridging of an injured spinal cord. Since the distance between proximal and distal stumps of the injured spinal cord cannot be large, there is no need to consider communication issues. Thus, one microelectronic system along with two microelectrode arrays may be enough to bridge an interrupted spinal cord. The situation for the channel bridging, the signal regeneration, and the motor function rebuilding of the paralyzed limb of a hemiplegia is some different: The controlled limb is the paralyzed one, while the controlling limb is the healthy one of the patient him(her)self or another healthy human. The large distance between the controlled and controlling limbs necessitates the function of communication or even telecommunication between two limbs.

FES applications were utilized as neuro-electrical and electro-neural interface, respectively, since they are both non-invasive and medically approved. Thus, neural signals were replaced by EMG signals.

For the communication system used in our experiments, both wired and wireless techniques have been developed. The simple wired system was used for the function rebuilding between two limbs of the same body or two bodies which are close with each other.

For the signal regeneration and function rebuilding between two far-separated nervous systems of toads mentioned above, the 3G technology was chosen. There are three advantages: (1) It is a wireless technology; (2) It is telecommunication technology; (3) It has a high bandwidth which is qualified for data transmission. That system consists of an AD converter, a DA converter, a USB circuit, a micro control unit, two notebook PCs and a 3G module. The analog signal from the neural signal detecting system is converted to digital format and then transferred to the 1st notebook PC where the data are transmitted through 3G mobile network to 2nd notebook PC. At the other side of the system, the digital signal is converted to analog signal again for the functional electrical stimulation system. Fig. 3 shows the photograph of a PCB module of the MENB for motor function rebuilding between two limbs with a communication system.

In animal experiments, live toads and spinal toads (with resect head or destroyed brain) were used, owing to their strong vitality. For experiments on human bodies, most

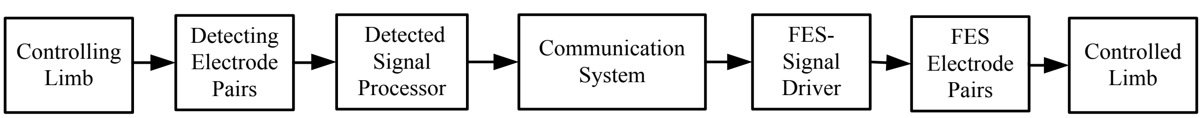

Fig. 2 Block diagram of the MENB for the motor function rebuilding of a hemiplegia

Accordingly, the block diagram for the reconstructed MENB shown in Fig. 2 has been developed. Here, instead of an interrupted spinal cord, two limbs are bridged by such a MENB system in which a communication system is inserted between the detected signal processor on the transmitter side and the FES-signal driver on the receiver side. In addition, the block coming before the detecting electrode pairs is indicated as controlling limb, and the block after the FES electrode pairs, as controlled limb. In experiments, both the neural signals from animal limbs and the electromyograph (EMG) signals from the arms and legs of health human subjects were detected as source signals, and both the animal nerve and the neuromuscular junction of health human are used as control objects.

Hook-type electrodes were used to form the interfaces of the animal nerves and the electronic system. For experiments on human body, surface electrodes for cardiograph and for

members of our team volunteered.

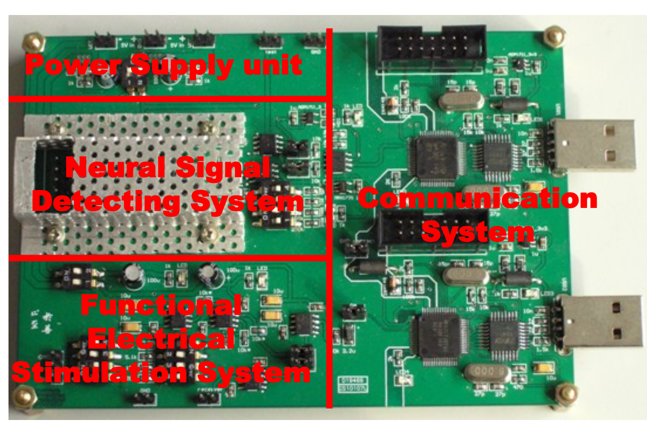

Fig. 3 The photograph of a PCB module of the MENB for motor function rebuilding between two limbs with a communication system

III. EXPERIMENTS AND RESULTS

As mentioned above, we have made an experiment of function rebuilding between two spinal toads which were laid on test tables in Beijing and Nanjing, respectively, two cities about 1000 km apart. In this experiment, the sciatic nerves of 2 toads were connected by two MENBs with communication system. After the left leg of the spinal toad in one city was stimulated by one drop of 5% acetic acid, it withdrew. The evoked neural signal was detected, amplified, transmitted to the FES circuit, applied on the sciatic nerve of spinal toad in the other city, and caused the toad to withdraw the left leg almost synchronously [8].

Even though that experiment was successful, the question whether the withdrawing was only a withdrawal reflection caused by the chemical stimulation arose. To answer this question, we have made such an experiment as shown in Fig. 4.

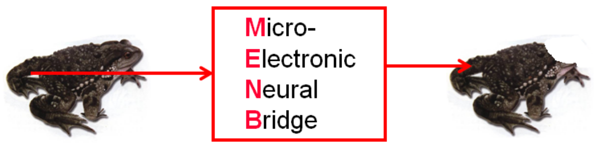

Fig. 4 Schema of a spinal toad controlled by a live toad

Here the sciatic nerves of a live toad and a spinal toad were also connected by one MENB. The result was that the spinal toad made a similar movement with both extension and flexion as the live toad did. With this animal experiment it was demonstrated that a function rebuilding is realizable when the nerve of a paralyzed limb can be connected to the nerve of a health limb.

Then, we have made such an experiment in that the hind leg of a spinal toad was controlled in real time by the EMG-signals detected from a human. Fig. 5 shows the photograph of a scene of the experiment. The most important feature of this experiment is that surface electrodes were used to detect the EMG-signal as the controlling signal for the nerve of a spinal toad, where a cuff-type electrode was used to make FES to one hind leg of the spinal toad.

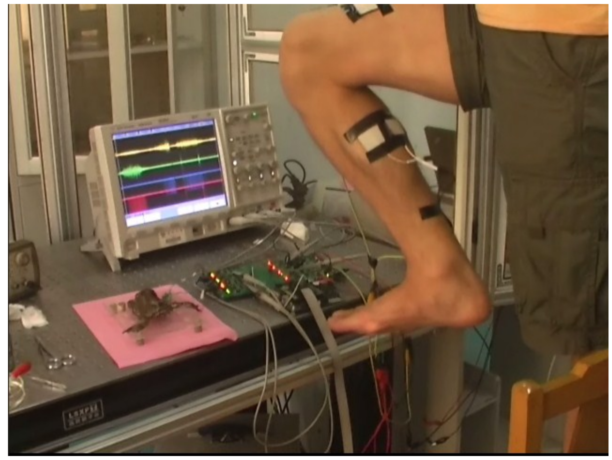

Fig. 5 shows the photograph of a scene of the experiment

It is interested that hind leg of a spinal toad can also be controlled coordinately by the arm of a human. The schema is shown in Fig. 6. Fig. 7 shows the photograph of a scene of the experiment according to the schema in Fig. 6. With this experiment it is demonstrated that for a single freedom of movement the signal pattern is important for the function rebuilding while the source is less important.

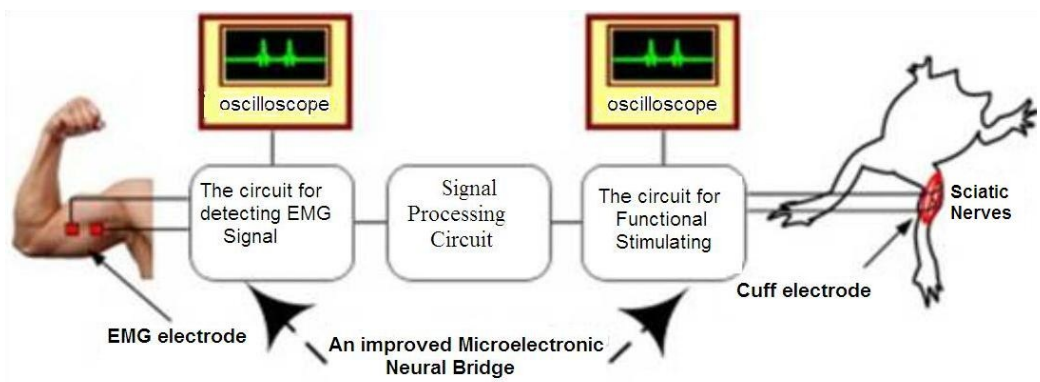

Fig. 6 Schema of the hind leg of a spinal toad controlled by the arm of a human

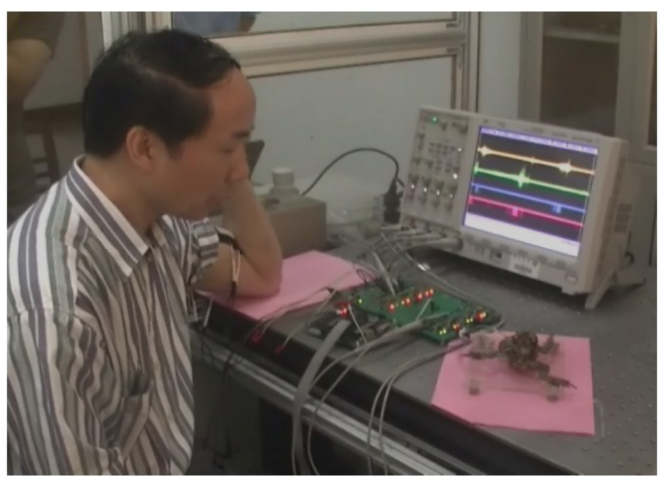

Fig. 7 The photograph of a scene of the experiment according to the schema

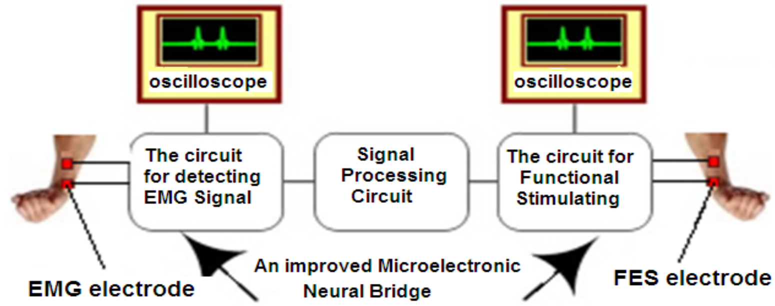

Fig. 8 Schema of the wrist of one healthy human controlled by the wrist of anther healthy human

Finally, we have made an experiment of the function rebuilding between two wrists of one healthy human according to the schema as shown in Fig. 8. Fig. 9 shows the photograph of a scene of the experiment according to the schema in Fig. 8.

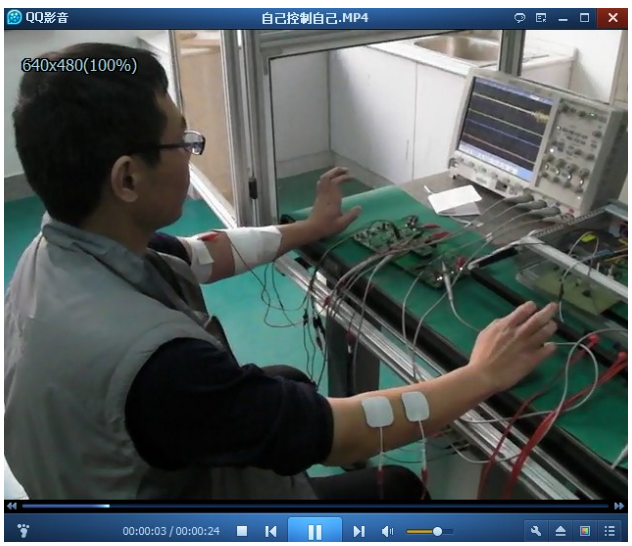

Fig. 9 A photograph of a scene of the experiment according to the schema in Fig. 7

This experiment has two important features:

1) Surface electrodes were also used to make FES on the skin of a human;

2) The motor function of one hand can be controlled by the other hand of the same person, what is just suitable for the motor function rebuilding of hemiplegic patient.

IV. CONCLUSION

In this paper our novel concept on function rebuilding for hemiplegic limbs and the primary experiments are reported. It is demonstrated that the motor function of an animal or a human can be rebuilt by using a multi-channel micro-electronic neural bridge (MENB). Inserting a communication system into the MENB, it is expected that the motor function of the paralyzed limb of a hemiplegic patient can be controlled by the healthy limb of him/herself or by the limb of another healthy human.

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