An Improved FES System for Control of Paralyzed Upper Extremity

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Abstract

This paper describes an improved FES system to restore paralyzed extremities in spinal cord injury patients. For composing stimulus pattern which is suitable for each muscle, electrical stimulus pattern creating system is also developed by using IBM-PC. In the improved portable FES system using V40 microprocessor, muscle fatigue can be decreased by selecting the stimulus frequency which is proper to the response characteristics of each muscle. Driving softwares for the portable FES system and the stimulus pattern creating system are programmed with assembler and C language. A multichnnel portable FES system is designed to minimize the size and weight using a D/A converter and 32 channel multiplexer.

I. Introduction

Paralysis of extremities occurs by various biological reasons of spastic paralysis or spinal cord injury due to traffic accident. Paralysis can't be restored by medical treatment or physical therapy. In order to move volitionally the muscles of paralyzed extremities, the electrical methods have been proposed. Especially, functional electrical stimulation (FES) has been developed to restore paralyzed upper or lower extremities. The FES is to make the voluntary functional movement by generating the contraction of multiple muscles as the electrical patterns similar to the EMG signal detected from normal muscles.

Peckham and Handa have been developing FES system.[1-3] But the contraction force is decreased in a long time stimulation, so that there is no movement. This situation is described as "muscle fatigue". The cause of muscle fatigue is not the metabolism in the muscle but the loss of transmitter substance in the neuromuscluer juntion due to unphysiological stimulation. The muscle fatigue is closely related with stimulus frequency so that we should adjust the stimulus frequency according to the characteristic of each muscle.[4] In the past, the fuction of adjusting frequency for minimizing muscle fatigue in portable FES system was not considered.[5]

Therefore, we proposed the portable FES system, in which stimulus frequency could be adjusted by driving a D/A converter and 32 channel multiplexer. This FES system is designed to minimize the size and weight for portability. Additionally, we developed the stimulus pattern creating system to compose stimulus pattern using IBM-PC. Driving softwares for the portable FES system and the stimulus pattern creating system are programmed with assembler and C language.

II. Medical Fundame[redacted]ls

To understand the technical detail[redacted]ystem, it is necessary to be familiar with some ba[redacted]facts.

Electrical stimulation generates an[redacted]ntial in nerve, so that muscle is contracted.[6] So, a [redacted]of stimulation to multiple muscle may move functionally paralyzed extremities. Fig. 1 shows movement mechanism of some muscles in forearm.

Interossei palmares and interossei dorsales : Fixation of the 2nd, 3rd, 4th, 5th fingers.
Deep radial nerve(unstimulus supinator) : Extention of wrist.
Deep radial nerve(stimulus supinator) : Supination of forearm.
Extensor digitorum communis : Extension of the 1st, 2nd, 3rd, 4th, 5th fingers and wrist.
Abductor pollicis brevis : Abduction of thumb and wrist.
Triceps brachii : Extention of forearm.

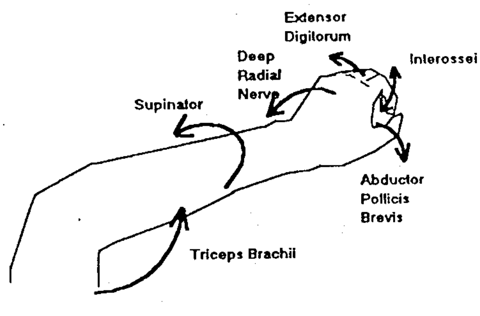

Fig. 1 Movement functions of muscles in forearm

Most of muscles are classified into slow muscle and fast muscle according to response speed to impulse stimulation. Slow muscle like soleus muscle responses slowly to stimulating impulse, on the contrary, fast muscle like medial gastrocnemius muscle reponses fast.

Ⅲ. Conformation of Stimulus Pattern Creating System

The stimulus patterns used in portable FES system are created from EMG data. The proposed stimulus pattern creating system is performed with widely supplied IBM-PC so that low cost is realized. The functions are as follows ; saving standard EMG patterns as files, copying from EMG patterns to stimulus patterns, detecting maximum and minimum stimulus amplitude, modifying the shape of stimulus pattern copied from EMG patterns, adjusting stimulus frequency according to each muscle and saving completed stimulus patterns as files. The data of created stimulus patterns are transmitted to the portble FES system through serial communication device using RS232C. All these functions are managed in united configuration.

Ⅳ. Construction of Portable FES System

The improved portable FES system is divided to five parts such as a contol part, a stimulation part, an in-output part, a power part and an electrode part. The control part consists of V40 microprocessor, ROM for stimulation program, SRAM for the allocation of data of stimulus patterns, RS232C for communication with the stimulus pattern creating system. The stimulation part with a D/A converter and a 32-channel multiplexer is drived to make stimulus patterns of each channel by time division multiplexing program in ROM. LCD to display system status and 4 keyswitches to input user's commands are used for friendly interfacing with the patients. The power is supplied with a battery and DC-DC converter in which voltage is variable upto 30[V]. The electrodes are inserted into muscles. Maximum diameter of electrode is 0.48[mm].[7] The specifications of stimulus pulse are as follows.

1) Maxmum stimulus amplitude is 30[V].
2) Duration of stimulus pulse is variable upto 0.4[mSec].
3) Frequencies of stimulus pulse are 10, 20, 40[Hz].

Fig. 2 shows the inner structure of the portable FES system.

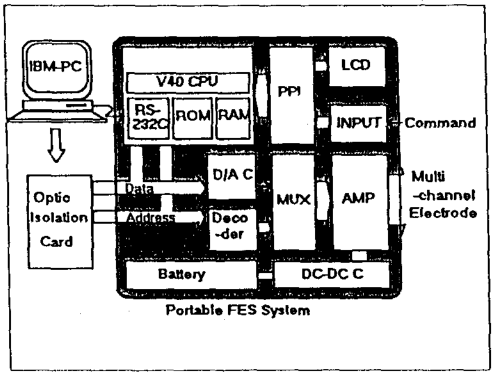

Fig. 2 The structure of the improved portable FES system

Ⅴ. Experiment of Muscle Fatigue

The measuring experiment of the muscle contraction force for wrist extention should be executed to investigate muscle fatigues with respect to some frequencies. Wrist is stimulated from 20[Hz] to 40[Hz] by the portable FES system. For measuring the muscle contraction force for wrist extention, we used the strain gages contacted to flexible plate on the wrist like Fig. 3. The amplified signal from the strain gages is observed by oscilloscope and peak voltage is checked.

Fig 4 shows the changes of wrist extention force in 40[Hz] and 20[Hz]. According to the result of experiment, muscle fatigue of wrist organized with fast muscles was more decreased in stimulation of 40[Hz] than in 20[Hz]. So that muscle fatigue can be improved by adjusting the stimulus frequency which is proper to response characteristics of each muscle.

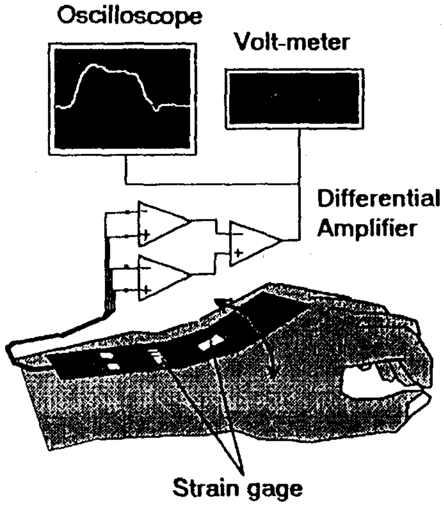

Fig. 3 Experiment of muscle fatigue

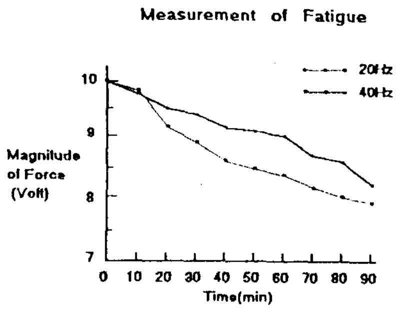

Fig. 4 Wrist extention force curve

Ⅵ. Clinical Application

The patient was 11 years old male child who had spastic hemiplegic cerebral palsy. Before operation, his wrist and hand was fixed contractedly and his elbow couldn't be straight. So, on July 1991, electrodes was inserted into muscles and nerves in left upper extremity. After the FES, spasticity of forearm muscle was decreased remarkably and wrist which had been fixed contractedly became flexible. The stimulus patterns of hand grasping and opening for basic activity of daily life were stored into memory of portable FES system so that paralyzed forearm could pick up a thing by stimulating the muscles. Fig. 5 shows the stimulus patterns for hand grasping and opening, and Fig. 6 shows the motion of picking up a thing by stimulation. Resultly, paralyzed upper extremity may be restored by controlling stimulus pattern.

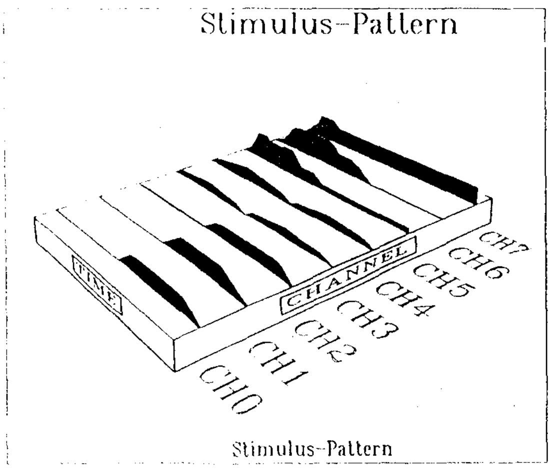

Fig. 5 Stimulus patterns for hand grasping and opening

Fig. 6 The motion of picking up a thing by controlling stimulation

Ⅶ. Conclusion

1. Muscle fatigue in a long time stimulation can be improved by adjusting the stimulus frequency which is proper to response charateristics of each muscle.

2. Time devision multiplexing method using a D/A converter and 32 channel multiplexer was proposed for minimizing the size and weight of the portable FES system.

3. The stimulus pattern creating system was developed for easy usage and is implemented with IBM-PC for low cost.

4. Driving softwares for the portable FES system and the stimulus pattern creating system are programmed with assembler and C language.

5. The proposed portable FES system proved to be very useful to restore fuction of paralyzed extremity.

Reference

1. Long C. and Masciarelli, "An Electrophysiologic splint for the hand", Arch. Phys. Med., 1963, pp.499-503.

2. Kevin L.Kilgore, P.Hunter Peckham, Michael W.Keith and Geoffrey B. Thrope, "Electrode Characterization for Functional Application to Upper Extremity FNS", IEEE Transactions on Biomedical Engineering. Vol 37. No 1, January 1990, pp.12-21.

3. Y.Handa and N.Hoshimiya, "Functional Electrical Stimulation for the Control of the Upper Extremities", Med. Prog. Techn, vol. 12, 1987, pp.51-63.

4. Byung Rim Park, Min Sun Kim, Sung Gon Kim, Ha Kyung Kim, Sang Soo Kim, "Effects of Intermittent Sciatic Nerve Stimulation on Muscle Atroply in Hindlimb Suspened Rats", Proceeding of the 1st International FES Symposium, July 1992, pp.23-29.

5. Y.Handa, K.Ohkubo, N.Hoshimiya, "A Potable Multichannel FES System for Restoration of Motor Function of the Paralyzed Extremities", Automedica, 1989, Vol.11, pp.221-231.

6. John G. Webster, Medical Instrumentation Application and Design, pp143-163, Boston, Houghton Mifflin Company, (1978).

7. Y.Handa, N.Hoshimiya, Y.Iguchi, T.Oda, "Development of Percutaneous Intramuscular Electrode for Multichannel FES System", IEEE Transactions on Biomedical Engineering, Vol.36, No. 7, July 1989, pp.705-710.