Application of Local EMG-Driven FES to Incompletely Paralyzed Lower Extremities

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Abstract

For FES control of incompletely paralyzed lower extremities, various rule-based methods have been proposed. However, the necessity for adequate reliability of sensors and walking phase detection have made such systems difficult to be widely used clinically. In this report, a simple "local EMG-driven FES" system is proposed and shown to be effective in knee extension FES for incomplete paralyses. In this scheme, e.g., knee extensor is electrically stimulated according to the magnitude of measured voluntary EMG from the same muscle, which is partially paralysed. Apparently this scheme is applicable only to incomplete paralyses, however, the number of corresponding patients is not small and the method is applicable not only to walking, but also to other daily activities such as transfer from bed to wheelchair or standing-up, without any control-mode selection for each consecutive activity to aid, because those EMG reflect the neural commands from the brain.

1. INTRODUCTION

For the incomplete paralyses of lower extremities, rule-based FES control which is based on gait phase detection with foot switches and/or acceleration sensors have been proposed and examined[1-5]. In those method, however, there seems to be a problem that the resulted gait improvement is not so satisfactory for the patients when compared to the expense of time and difficulty in setting-up sensors and stimulator accurately. Additionally, those control algorithms should include bothering mode-switching. Therefore, simpler, but still effective FES control method is needed to be developed for some kinds of paralyzed patients.

In this report, a very simple "local EMG-driven FES" is proposed and shown to be effective in knee extension FES for incomplete hemiplegics by stroke. In this scheme, e.g., knee extensor is electrically stimulated according to the magnitude of measured voluntary EMG of the same muscle. Resulted voluntary muscle force is expected to be reinforced naturally and if it is applied to a muscle of which the maximum tension is not sufficient, this FES can be expected to aid the patient's daily activities such as crutch-walking, transfer from bed to wheelchair, or standing-up, without any bothering mode selection. This method is a kind of EMG-driven FES[6-8] and the idea itself is trivial, however, successful clinical application has not been reported, although the circuit design has been reported for the case in which the EMG detection and electrical stimulation share a same pair of electrodes[9]. In the method shown below, two independent pairs of electrodes were used for EMG detection and FES, to make it easier to suppress the artifact from surface stimulation to voluntary EMG detection.

2. METHODS

2.1. Basic design of the controller

To realize the surface FES and EMG detection to/from a same muscle, control system shown in Figure 1 was designed and examined. The system includes EMG electrodes, gating (protection) circuit, EMG amplifier, note PC with AD/DA card, surface stimulator and stimulating electrodes. The timing chart of the control is shown in Figure 2. Each amplitude of repetitive (20Hz) electrical stimulation of 500 micro seconds width was modulated by the power of voluntary EMG in each preceding period. Each stimulation pulse was paired by opposite polarity pulse so as to reduce the harmful transient effect onto EMG detection and also to reduce the long term electro-chemical change in electrodes. The EMG power of each segment was calculated from the samples for 20ms after subtracting the offset

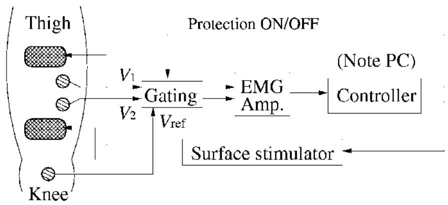

Figure 1. Local EMG-driven FES

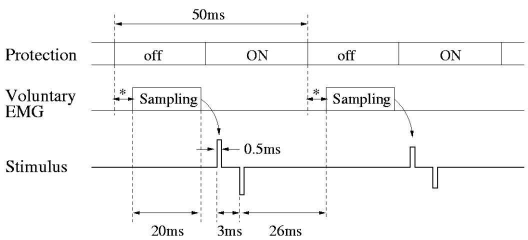

Figure 2. Timing chart of the control

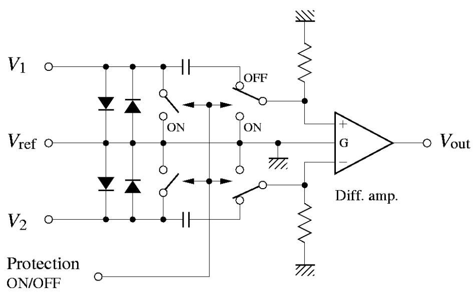

Figure 3. Gating (protection) circuit

level. Thus the resulted value corresponded to a "short-term standard deviation" of the EMG. A saturated threshold function was used for translating voluntary EMG power into FES amplitude. Sampling frequency of 1kHz was used for the RT-Linux PC as a controller.

2.2. Design to reduce artifacts

To protect the input stage of EMG amplifier from the damage by surface FES pulses, and to reduce the transient artifact, a gating circuit shown in Figure 3 was designed and examined. Due to the nonlinearity of silicon rectifiers, succeeding CMOS analog switches and amplifier can be protected from breakage. We also examined the effect of M- and H-waves. As a result of preliminary test for normal subject, it was confirmed that the time window design in Figure 2 was sufficient for use in lower extremity muscles (Significant H-wave could not be observed in knee extensor stimulation).

Figure 4. Clinical evaluation

2.3. Electrode arrangement

As the magnitude of artifacts from FES pulses to EMG measurement depends on the arrangement of each electrode pairs, we examined and compared several electrode arrangements experimentally. As as result, it was shown that in any arrangement including the case in which the EMG electrodes were sandwiched between FES electrodes, voluntary EMG could be clearly detected in the presence of adequate stimuli. Therefore, we adopted the arrangement to maximize the amplitude of voluntary EMG, by putting the electrodes in the direction of EMG propagation in muscle fibers.

2.4 Preliminary clinical tests

Three male subjects of 61 to 87 years old with hemiplegia by stroke participated in preliminary clinical evaluation of the system. Their voluntary knee extension forces were not sufficient to walk without crutch, and the speed of crutch-walking was very low. The subjects were applied the local EMG-driven FES described above to their quadriceps to improve the stability, speed and stride of their crutch-walking. The size of the surface FES electrode was 7cm x 9cm. EMG signal was measured at vastus medialis or rectus femoris, depending on the amplitude of voluntary EMG. Ankle foot orthoses were used for the paralyzed side.

3. RESULTS

For the two of three subjects, we could confirm that the walking stability was improved by local EMG-driven FES, and the subjective evaluation by patients were something like "this is helpful". For one other subject, noticeable improvement was not observed, and later it was confirmed that the noise from AC power line heavily affected EMG measurement because

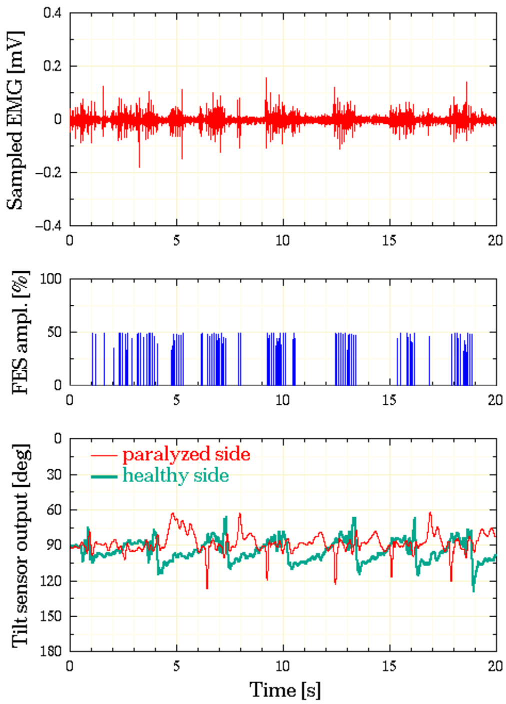

Figure 5. Example of walking with local EMG-driven FES (From the top, EMG, stimulation, and the outputs of tilt sensors at paralyzed and healthy side of shanks are shown.)

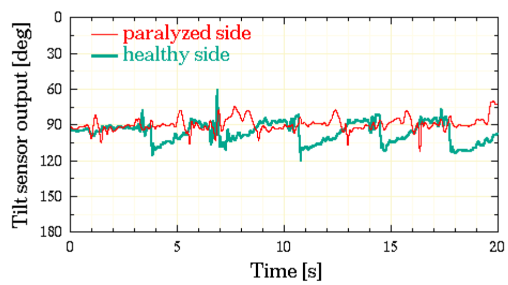

Figure 6. Example of walking without FES (Subject is the same as for Figure 5)

there happened attachment failure between EMG electrode and skin.

One of the results is shown Figures 5 and 6, from which we can confirm that the electrical stimulation was appropriately controlled by the sampled voluntary EMG signal. From the comparison of Figures 5 and 6, it can be also confirmed that the walking symmetry of the paralyzed and healthy side lower extremities was improved to some extent.

4. DISCUSSION AND CONCLUSIONS

A simple and easy-to-use local EMG-driven FES system was developed and examined. Although the clinical tests were subjective and limited for a small number of patients, the basic effectiveness of the idea was confirmed for the hemiplegic patients' crutch-walking.

With further development, we believe that a method to treat the EMG electrode failure could be found and controller could be implemented as battery-operated portable box. Using those controllers, quantitative evaluation of long-term effect of this control method should be carried out for various types of paralyses and objective motions in the near future. Application for completely implanted FES device should also be done.

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