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A Novel EMG Feedback Control Method in Functional Electrical Stimulation Cycling System for Stroke Patients

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***Abstract*—**With getting older in the whole population, the prevalence of stroke and its residual disability is getting higher and higher recently in Taiwan. The functional electrical stimulation cycling system (FESCS) is useful for hemiplegic patients. Because that the muscle of stroke patients is under hybrid activation. The raw electromyography (EMG) represents the residual muscle force of stroke subject whereas the peak-to-peak of stimulus EMG indicates the force enhancement benefiting from ES. It seems that EMG signals could be used for a parameter of feedback control mechanism. So, we design the feedback control protocol of FESCS, it includes physiological signal recorder, FPGA biomedical module, DAC and electrical stimulation circuit. Using the intensity of real-time EMG signal obtained from patients, as a feedback control method for the output voltage of FES-cycling system.

***Keywords*—**Functional Electrical Stimulation cycling system, EMG, control protocol.

I. INTRODUCTION

ACCORDING to the report of World Health Organization, there were 17,500,000 people died due to cardiovascular disease in the whole world in 2005, it is about 30% of global mortality. Among the death, 7,600,000 people died of the heart disease, 5,700,000 died of the apoplexy. By 2015, nearly 20 million people will die of heart disease and apoplexy. [1]

The disability after stroke has become painful for the patient and heavy burden to the patient's family and society. Rehabilitation therapy is the only hope to improve the patient's condition. The phenomenon of hemiplegia resulted from stroke is usually the suddenly neural damage, it can be control, overcome, or resume functions by using medicine and rehabilitation programs for a long time. But muscle will cause atrophy if muscle lack of activity, even if the neural function will resume being unable to control the muscle activity, and the functional electrical stimulation cycling system is designed for this purpose.

Functional electrical treatment (FET) has emerged as one of major rehabilitation modalities for subjects with motor disorders to provide enhanced functional activities. The beneficial effects of cycling exercise via functional electrical stimulation (FES) have been demonstrated to improvement of cardiopulmonary function, augment muscle forces and to improve human motion of populations with muscle disabilities, such as stroke, and incomplete spinal cord injury [2]. For stroke subjects, the muscle is under hybrid activation. The muscle force generated is from the combined volitional and electrical stimulation (ES). The raw electromyography (EMG) represents the residual muscle force of stroke subject whereas the peak-to-peak of stimulus EMG indicates the force enhancement benefiting from ES. However, the recorded EMG signals during stimulation of a stroke subject exerting a movement are the combination of the volitional and the induced components.

This research is designed for constant-speed motor-drive cycling system which is usually used by low limbs paralysis or stroke patients. This system used ADinstruments Powerlab physiological signal recording system combined with Chart software to deal with the EMG signals, using the intensity of real-time EMG signal obtained from patients, converting the data into digital formats, dealing the data with FPGA biomedical module, then convert the data into DAC code, through the electrical stimulation circuit to stimulate the muscles.

The system that this study presented here is to measure EMG signal that got from the human body using the recorder of the physiological signal, analyze which kind of state it will be representative, deal with the EMG signal according to different state and then, output different state code value, send into FPGA module to operate, use the operation result to control electrical stimulator.

The aim of our study is utilizing the intensity of real-time EMG signal obtained from patients, to develop a feedback control method for FES-cycling system.

II. SYSTEM ARCHITECTURE

A. Whole Systematic Structure

This system include four components those are physiological signal recorder combined with Chart software, FPGA

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biomedical module, DAC and electrical stimulation circuit, as shown in Fig. 1.

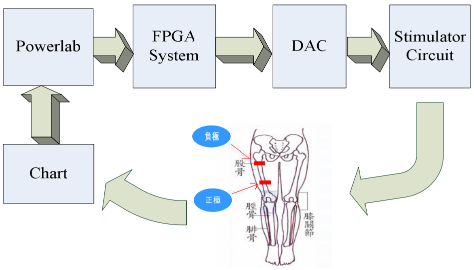

Fig. 1 Block diagram of whole system

The first component convey EMG signal that recorded from the physiological signal recorder to Chart software, make tentatively treatment and output several digital codes in the software. The second component sent previous data into FPGA systematic core and make operation to. The third component deals with the materials and sends into DAC doing the movements of the compiled code. The fourth component decodes according to DAC result, and export electrical stimulation to stimulate the human body.

B. Physiological Signal Recorder

The physiological signal recorder is a multi-functional analytical instruments, it can be used for recording the oxygen density of blood, heartbeat, EMG and respiratory rate, and so on. This physiological signal recorder offers the major input parameter of the system.

C. FPGA Biomedical Module

The biomedical module we used in this system is the Altera EP1K30TC484-3 FPGA development board. This development board utilizes print port interface to connect with computer, there are one ADC and four channels of electricity stimulating devices, the electricity stimulating device can join simulate human body's load, it can observe the effects of electrical stimulation directly, and is not necessary applying the real electricity into the human body.

D. Electrical Stimulator

Electrical Stimulator is combined with pulse generator, DAC, and stimulating circuits, as drawn. Pulse generator can arbitrary to adjust necessary frequency and wave wide, and DAC are used for adjusting the amplitude of output, if the output of the amplitude is bigger, then the export of electricity stimulates will also bigger. Our electrical stimulator provided monophasic rectangular pulses of 300 µs at a frequency of 20 Hz. The maximum constant current output can up to 40 mA.

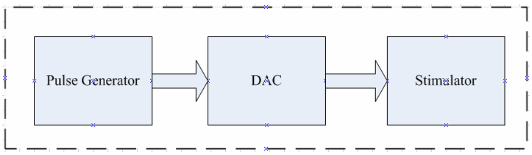

Fig. 2 Electricity stimulator block diagram

III. Methods

A. Measurement of EMG Signals

When muscle contracts, the electric potential signal will produce and the amplitude is positive relative with the size of activated muscles at that time. Electromyography is a technique concerned with the development, recording and analysis of myoelectric signals. The EMG was monitored using three surface electrodes (contact diameter of 2.2 cm, external diameter of 3.6 cm): two electrodes were located on the muscle belly along its longitudinal axis at mid-distance between the ES stimulation electrodes; the distance between the electrodes was 6 cm center-to-center [2]. The ground electrode was placed on the bony medial epicondyle area of the femur. The sampled EMG signals were transmitted to PC through the Powerlab converter at a sampling rate of 5 kHz for data storage and signals processing. EMG that direct quantity examines is called Raw EMG; it should be processed, and then be accepted by this research. [2][3][4]

B. EMG Signals Processing

EMG is very apt to be interfered with by the electromagnetism. During the electrical stimulation period, it will produce great artifact, cause signal judge difficult, so we must filter the wave to find out some more observed signal. First, to eliminate the M-wave and stimulus artifact, the overall EMG signal was high-passed filtered (cutoff frequency of 20 Hz). Then, the EMG was filtered (narrow band pass filter, 20 Hz) to generate the EMG envelop. The artifact can't totally be removed after filtering the wave, but can minimize influencing. [5][6].

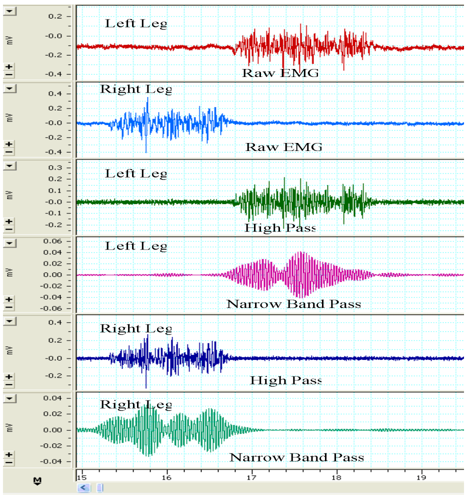

Fig.3 EMG signals processing

C. Levels Setup

Using Chart software and set up the level, fetches a rational range for the signal, it is usually scheduled inside between 0.02-0.06mV, makes three suitable patients' level respectively of left and right foot. Make behind the stratum, utilize software to set up and determine which digital codes should be outputted when the level reaches.

When signal reaches the first level, but does not reach the second, and the third level, the instrument will export digital codes 001; when signal reaches the first level and the second level, but does not reach the third level, the instrument will export digital codes 011; when signal reaches the first, second, the third level, export 111, when not reaching any level, export 000, as shown in Fig. 4.

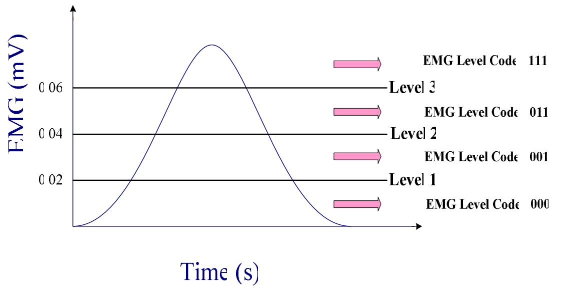

Fig. 4 The sketch map of level outputs

D. FPGA Systematic Core

The main functions of this component are judging the level, control system and DAC set up. Level judgment encode several signals, count the times of special digital codes, every level has the basic number of times that must be reached within two seconds, if reached, judge the myoelectric signal has accorded with this level, if has not arrived, will judge the signal of this level is too faint, does not list in calculating, and will export 0. So, there will be 000, 001, 011, 111, four kinds of output forms, represent four levels. Confirm the level, and send result to the control system, control system will differentiate how much DAC analyze degree should give DAC and the electrical frequency and wave width. The frequency is 20 Hz, wave width is 300 µs. And DAC also responsible to analyze the coming DAC code, then control electrical stimulation output, as shown in Fig. 5.

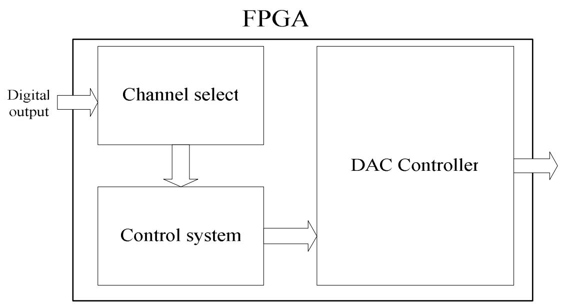

Fig. 5 The block diagram of FPGA systematic core

(a). Level judgment

Digital encoder sent 6 EMG energy codes, every bit represent one level, the first three bits represent of left foot, the last three bits are the right foot. We should examine whether the counting numbers of each level in two seconds reaches the basic number of times, the basic number of times of each level is all different, so must find out the number of times that each level need. Find out the each number of times that level represent, if the number of times greater than the basic number of times of the third level, export 111; if not, then check the second level, export 011; if not, check the first level, export 001; if no level is matched, export 000. As confirm three EMG energy levels, then send message to control system and dealing with, as shown in Fig. 6.

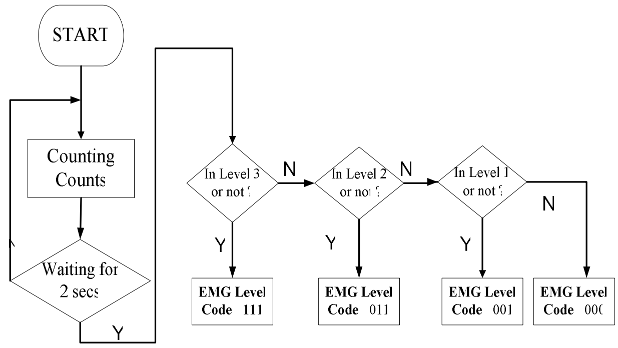

Fig. 6 The flow diagram for level judgment

(b). Control system

When EMG energy level is determined, and system sends the correct code of left and right foot signal, it is necessary to judge the level and the stimulated foot in time, then send DAC signal to DAC and exported for stimulating device. The stimulating frequency is 20 Hz, wave width is 300 µs. It is important to judge whether it is wrong signal or not, as left and right foot being all 111 or 000, it should be a wrong signal, such as Fig. 7. If the patient uses the FESCS normally, it must be impossible that left and right foot exert simultaneously, or not exert at the same time. This is a protector for FESCS, which can prevent too large unexpected electric current under abnormal conditions.

(c). DAC controller

When system sends EMG energy level code to DAC controller, DAC controller will encode the signal and choose which stimulating channel to be sent, DAC controller can control the value of level accurately and which channel should be represented in that time, then the electrical stimulating device will produce the electric current in the human body.

(d). Examples

1. When Chart software receives the signal between 0.04-0.06 mV, controller send 011 to FPGA systematic core.
2. FPGA receive 011 signal, then begin to count number of times, if count number of times reach 4500K, exports 011; if less than 4500K, determine the level with sequent.
3. After exporting 011 for the control system, the control system will export corresponding EMG energy code 0101_0101_0000_00 to DAC controller.
4. DAC controller can compile the code and set up 0.96V for electrical stimulating device to export, and the device will export 40V on human body.

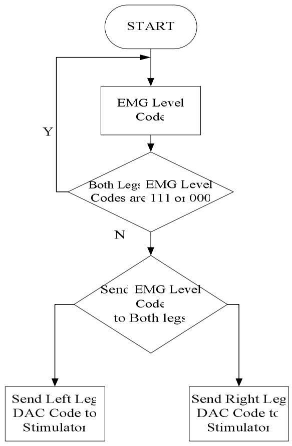

Fig. 7 DAC code procedure

IV. RESULTS

A. Whole Procedure

When the physiological signal recorder obtains the EMG signals, through the Chart software, digital codes are sent to FPGA core, the codes are then deal with level judgment and set up EMG energy level codes, 000, 001, 011, 111, one of these four codes. This code will be sent to DAC controller and analyze which degree of intensity and channel to choose at this moment, and set the pulse width and frequency. After DAC controller accepts these values, it will send the electrical current and stimulate the human body.

B. Verification of Result

Comparing the received EMG energy level that got from logic analyzer with the intensity value of electrical stimulating device following Figs. 8, 9, 10 list below are the first, second and the third steps separately.

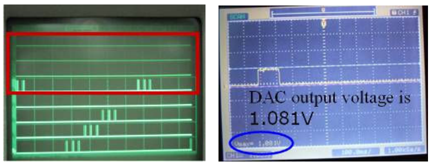

Fig. 8 The first level input and the result

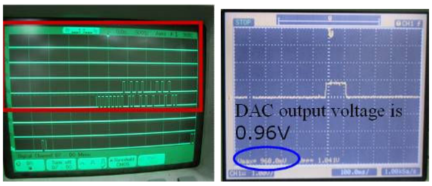

Fig. 9 The second level input and the result

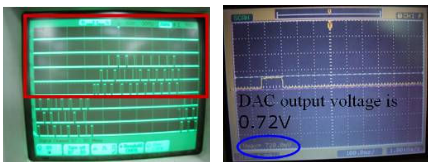

Fig. 10 The third level input and the result

V. CONCLUSION

This study is quite suitable for utilizing and applied to clinics. Using the intensity of real-time EMG signal obtained from patients, as a feedback control method for the output voltage of FES-cycling system. Combining with constant-speed motor-drive cycling system which is usually used by low limbs paralysis or stroke patients and our EMG feedback control system of FES, it is not necessary to buy an expensive cycling device with angular encoder. Every simple constant-speed motor-drive cycling system will suitable for this purpose. For the hemiplegic patient with low limbs paralysis, functional electrical stimulation cycling system is still a very useful rehabilitation tool. We hope that this novel EMG feedback control system could serve as a control protocol for FES-cycling.

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