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A DIGITAL SIGNAL PROCESSOR BASED FUNCTIONAL ELECTRICAL STIMULATION SYSTEM WITH ITS USER INTERFACE DESIGN

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Abstract- **This study proposes a digital signal processor (DSP) based functional electrical stimulation (FES) system with multi-channel and programmable design. Also, the element-envelope method is used for flexible and arbitrary waveform generation in real-time. In addition, we use LabVIEW software which is the graphical object-oriented language to design a toolbox for clinical users who are not familiar with the conventional text-based languages. With the user-friendly man-machine interface and toolbox design, they can develop their own user interfaces for the experimental or clinical studies easily. The proposed FES system compared with others shows the superiority and versatility in waveform pattern generation, feedback processing capabilities and the user-friendly man-machine interface design.**
***Keywords* - FES, DSP, man-machine interface, LabVIEW**

I. INTRODUCTION

The purpose of functional electrical stimulation (FES), or neuromuscular electrical stimulation (NMES), is the restoration and maintenance of the voluntary control of movements in patients who have central nervous system dysfunction, spinal cord injuries (SCIs), and for whom no normal recoveries are expected. All clinical applications of electrical stimulation demonstrate the principle that electrical stimuli onto the peripheral nervous system can generate controlled contraction of skeletal muscle. FES can be applied to improve the control of movements used for manipulation, grasping, locomotion, and posture control, etc.

Due to the advances in computer technology, many electrical stimulation systems have been developed for different kinds of applications, and they have been showed the feasibility and versatility of themselves [1]-[4]. But their functions are still confined in the specific applications. They may lack flexible pattern generation capabilities somehow. Besides, their driving stage can't provide high-voltage compliance and linear voltage-to-current conversion in the same time. Most of these stimulators' functionality designs and user interfaces are usually written in C languages or low-level assembly. These kinds of designs might be good for those engineers familiar with computer languages. However, to the majority of physicians and clinical workers, there exists a tremendous gap between the time required to learn C languages and the time it takes to develop the man-machine interface. It seems that a high-level programming system would be better than the low-level assembly or C languages commonly used. If possible, a FES system design should also include the graphical user interface (GUI) facilities that would make users familiar with their experiments more easily.

Because of the conventional difficulties described above, in this paper, we try to illustrate a multi-function FES system with its user-friendly man-machine interface. We also design a useful toolbox for the GUI programming, which is written in LabVIEW software (National Instruments Corporation). Finally, we will have a simple experiment for the upper limb function restoration with our FES system.

II. MATERIALS AND METHODS

In our proposed system, there are the following features: multi-channel mode, flexible and programmable patterns, high-voltage compliance and constant-current driving stage, electrical isolation, and user-friendly man-machine interface designed for the clinical users. Now we will show the superiority and versatility of our FES system, and the innovative user-friendly man-machine interface step by step.

1) Electrical stimulation system description

The proposed electrical stimulator is designed based on the digital signal processor (DSP) which is used to generate patterns with its high-computation capabilities (TMS320C32, Texas Instruments). The stimulating waveforms could be generated in real time with the element-envelope method proposed to synthesize stimulation patterns [5]. A DSP with its powerful computing capabilities was chosen to generate the patterns. The proposed electrical stimulator was well discussed in the aspects of waveform generator, driving stage design, and electrical safety consideration in [5]. The specifications of the proposed FES system were summarized in **TABLE I**.

On the other hand, we designed a user-friendly interface in LabVIEW software for the clinical users. LabVIEW is a graphical object-oriented language that is easier for the clinical users and non-professionals to use than the conventional text-based programming languages, and the basic entity of this program is the virtual instrument (VI). In this respect, we developed a useful toolbox with subroutine VIs. There were three VIs for the proposed electrical stimulation system, including "DSP-initiate.vi", "Stimulator-RS232.vi" and "Close-Stimulator.vi". The protocol of "DSP-initiate.vi" included sending bytes to the DSP for initialization, defining the port number, and checking the communication between the host computer and the DSP. The protocol of "Stimulator-RS232.vi" included rechecking the communication between the DSP and the host computer, defining channel (1-8), current (0-127), pulse width (0-6350), and offset (0-7). Finally, the protocol of "Close-Stimulator.vi" included checking the serial port and sending bytes to the DSP for termination.

2) Simple experiment demonstration

We had used this proposed FES system to design a simple experiment. In our case, we wanted to restore the upper limb function of the SCIs or related neural impaired patients. Also, we wanted to get the joint angles of fingers and grasping forces as feedback signals. The CyberGlove (Virtual Technologies, USA) was used to measure the angle signals of hand joints in real-time. Besides, the CyberGlove could be used to monitor the sequences of hand opening and grasping. These feedback signals were gathered to produce more smooth control for the FES system.

III. RESULTS

The proposed FES system was with versatility and feasibility from the viewpoint of its hardware and software design. Our FES system has been evaluated in many groups in Taiwan, including shoulder joint control, pedaling wheelchair system, muscle profile analysis, gait pattern training, and gastric function restoration. Moreover, in our system, the users could program their own man-machine interfaces easily due to the useful toolbox designed by LabVIEW. From our simple experiment, the proposed FES system restored the grasping and releasing function successfully. The sequences of motions were also detected by using the CyberGlove. On the other hand, the users could handle the FES system easily just by utilizing the GUI after they setup the stimulation parameters. In addition, they could start these channels simultaneously or individually by their requirements.

IV. DISCUSSION AND CONCLUSION

The proposed DSP-based FES system with multi-channel and programmable design was successfully developed. The FES system shows great flexibility because of a powerful DSP was used to synthesize waveforms by the element-envelope method. With this method used and implemented by the DSP, the arbitrary waveforms could be generated in real-time. The proposed stimulator also had the constant-current source which could provide the bi-phasic and linear voltage-to-current output with high-voltage compliance.

The physicians usually use electrical stimulators for clinical studies, but they might not be familiar with the C languages for designing their own studies. For this reason, we try to develop a FES system with the user-friendly man-machine interface design in LabVIEW which is a objected-oriented language. In other studies, LabVIEW is also used due to its powerful alternative for scientific and biomedical engineering programming [6]-[8]. In this paper, to make the proposed FES system more flexible and friendly, we wrote a communication protocol and implemented a special command set. A host computer could directly control the stimulator via standard RS-232 interface with these commands. The users could conveniently change the stimulation parameters, such as current, pulse width, on-and-off time, and total stimulation times. Moreover, from our simple experiment described above, a close-loop FES system could be implemented easily with this useful design.

In summary, the proposed system can be considered as a versatile and full-featured stimulator for various applications with its high flexibility in pattern generation and multi-channel design. Most importantly, the FES system and its man-machine interface are linked by LabVIEW. This would be helpful for clinical users when designing experiments.

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TABLE I

The specifications of the proposed electrical stimulator

Number of channels	4
Output mode	Constant-current
Current output	0~110mA
Maximal output voltage	± 88V
Time resolution	50 us
Duration range	50~1000 us
Frequency range	3~100 Hz
Envelope points	Up to 10000 points
Data link with host computer	RS-232, 19200 bps
User interface design	LabVIEW software
Software platform	Windows 95/98/Me/NT/2000