DEVELOPMENT OF A PORTABLE COMPUTERIZED FES CONTROLLER

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ABSTRACT

There have been many studies made about the functional reconstruction of patients suffering from motor paralysis by the functional electrical stimulation (FES). But the clinical application of this FES is limited to the case when a simple or a repeated stimulation pattern is sufficient to reconstruct the motor function, because there exists no small size FES controller which has the ability of generating complex stimulus waveform pattern or changing its pattern according to the occasional change in circumstances.

From this point of view we have developed a portable computerized FES controller system. This system is a battery-driven computer small in size and it consists of minimum number of elements necessary for the control of FES, such as a CPU (Z80), 8 Kbytes RAM and a D/A converter.

Keywords - Paraplegia, Motor Function, Rehabilitation, Functional Electrical Stimulation (FES), Microcomputer.

INTRODUCTION

The FES has been proved to be effective in the functional reconstruction of patients suffering from various functional motor paralysis (1). But most FES controllers widely used are hardwired and have almost no flexibility of changing its output waveform, or too big to be carried by the patient (2).

And also we have developed a portable biosignal recording and analyzing system, called MICRO (Medical Information Collection RObot) (3), (4), (5). The MICRO is a kind of portable battery-driven computer and this system can automatically record and analyze various kinds of medical information.

In this study we have developed a portable computerized FES controller, MICRO-FES, with the technology used in this MICRO system.

SYSTEM DESCRIPTION

Figure 1 shows the principle of FES with the use of this MICRO-FES system. The MICRO-FES system is designed to stimulate directly the paralyzed muscles with implanted electrodes through a skin terminal (6), but it does not have the ability to stimulate them through surface electrodes.

Of course all elements necessary for the control of movements of paralyzed muscles are intended to be implanted inside the patient's body in the next system intended, including a CPU, memories, an A/D converter for gathering many kinds of biosignals, a D/A converter for stimulating muscles, and electrodes.

But main purpose of this study is to clarify what ability this kind of implanted system should be equipped with, or whether this computerized system has the sufficient ability to control the movement of paralyzed muscles. For this reason this MICRO-FES system has no means of gathering any kinds of biosignals. In this study, the efficiency test of MICRO-FES system is the main theme.

General Structure of MICRO-FES System. Figure 2 shows a portable unit, the main component of the MICRO-FES system, and an interface unit, while figure 3 shows the configuration of this system.

As shown in figure 3, this MICRO-FES system consists of a portable unit worn by a patient and an interface unit that connects this portable unit with the host computer. The PC-9801 16 bit personal computer (NEC CO. LTD., Japan) with Z80 emulation board was used as this host computer.

The portable unit is a kind of small battery-driven computer, which size is about 13 * 9 * 4 cm and weight about 200 gr. As shown in this figure 3, this unit consists of minimum numbers of elements necessary for FES, such as a CPU (Z80, 2.5 MHz), 8 Kbyte memories (static RAM), a real time clock, a D/A converter and analogue multiplexors.

CMOS processed ICs or LSIs are used for all elements constituting this portable unit, and consequently this unit can be driven by small batteries (9 volt, 006P type * 2: one for the CPU board and for plus voltage supply of the stimulus generator and the other for minus voltage supply of this generator). Moreover, this system is so designed as the halt instruction cuts the clock pulse supply to the CPU and stops the operation in order to restrain unnecessary electrical power consumption, like the power consumption between each stimulation period.

One feature of this system is that memories inside the portable unit are all RAM, that is, a readable/writable memory. Therefore any FES control program needs to be transmitted on memories of the portable unit from the host computer as occasional calls. The reason of this feature is that the control program must be changed frequently according to its purpose of FES. In contrast with widely used methods that the control program is fixed in read only memories (ROM), the control program can easily be changed. Moreover, the duration necessary to develop a control program becomes seriously short because this program can easily be rewritten when some trouble is found in this program. As long as the FES is concerned, the MICRO-FES can be said to have the ability almost equal to any other 8-bit micro computer system on the market.

Meanwhile, the main role of the interface unit shown in figure 3 is to transmit a control program from the host computer to the portable unit. This interface unit consists of an IPL-ROM, in which an initial program loader and a transmitting program are stored, and an UART, which controls the RS-232C serial line interface.

Because this system has these features, the two following steps of procedures, shown schematically in figure 4, are necessary for an actual use: 1)attaching the portable unit to the interface unit and transmitting the control program from the host computer to the portable unit, 2) after detaching the portable unit, putting this unit on the patient and starting its operation.

Almost all popular computer systems on the market can be used as the host computer but not for the developing of measurement program, because these computer systems usually have RS-232C serial line interface. The maximum transmitting rate of this serial interface is 38.4 Kbps.

Further, the CP/M-80 operating system widely used in 8-bits micro computer system can run on the portable unit by connecting the BIOS (basic input/output operating system) of the CP/M operating system on the portable unit to the BIOS on the host computer through RS-232C serial interface. Therefore many convenient softwares, like a real time debugger, can be used without any change, and stimulation control programs can be developed more easily.

System Hardware. Figure 5 shows the hardware configuration of the stimulus generator of portable unit, which corresponds to the stimulus generator briefly shown in figure 3. In MICRO-FES system, eight nerve-muscle dynamics are stimulated in electrically isolated manner through two synchronously selected analogue switches of two analogue multiplexors (the upper half). Of two analogue switches the selection of channel pair that is open, is controlled by the CPU through digital output. Simultaneous stimulation of two or more muscles can be realized by rapid change of this selection channel.

The lower right half is a current regulator, which regulates the current flowing through two analogue switches selected and the objective nerve-muscle dynamics. The current amplitude can be controlled by the CPU through an 8 bit D/A converter but the maximum current amplitude also can be adjusted by a full scale adjuster, shown in the dotted frame.

This system has the maximum current supply ability of 10 mA (the maximum value in this system) to about 1 KΩ or 1 mA to 15 KΩ impedance of nerve-muscle dynamics with 8 bit resolution (about 40 μA for 10 mA and 4 μA for 1 mA).

Application Softwares. As mentioned above, both the current amplitude and the stimulation channel can be changed in real time by the control program loaded on the portable unit, and any complex stimulus waveform pattern can be achieved by the change in this control program.

Figure 6 shows an example of stimulus waveform pattern. The abscissa shows the time and the ordinate the current amplitude of each of the four channels. In this example, a pulse-shaped stimulus with pulse width (PW) appears repeatedly at some inter-pulse interval (IPI). The current amplitude of each pulse of every channel stimuli is designed to be changeable in this example. And the IPI also can be changed at any time of inter periodic interval. The periodic interrupt is accurately generated by the real time clock, shown in figure 3, and then the IPI can be accurately set. A periodic interrupt frequency of 2048 Hz (minimum IPI is about 0.5 msec) is chosen as this interval, but this interrupt frequency also can be changed as occasional call.

Figure 7 shows a flowchart of the interrupt routine of this FES control program example. The smallest loop is the one which generates one pulse of some selected channel. The minimum PW is acquired by setting initial p.w. count to 1, and was measured about 4 μsec. This is the limit of this system using Z80 (2.5 MHz) CPU. Of course this PW can be increased by increasing initial p.w. count value.

The outside loop is the one that scans all channels, and at the end of this loop, all of the pulse of every channel are completed. The upper comparing routine is established for deciding the IPI.

The greatest feature of this example is that the current amplitude of each pulse of each channel at each stimulation period is previously prepared in a pulse train schedule table on the memory of MICRO-FES portable unit. Figure 8 is the configuration of this pulse train schedule table. The size of this table is 6144 bytes and the table is stored on the memory, shown in the left upper half in this figure. The structure of this table is shown in the upper right half. Each current amplitude of each channel pulse is prepared in series in this table, and the FES control program reads this stored data one after another in the loop of pulse stimulus generating routine, the smallest loop shown in figure 7.

The lower half is an example of pulse stimuli waveform of each four channels prepared in this table. The abscissa shows the time and the ordinate shows the current amplitude of each channel.

The upper trace is a case when the IPI is constant, but the current amplitude gradually increases, constant for some period and gradually decreases. The next trace is a case when the current amplitude is constant, but the IPI gradually increases, constant for some period and gradually decreases. This change of IPI can be realized by setting the first pulse having some value, second zero, third zero, fourth some value and so on. The last two traces are cases when both the current amplitude and the IPI change.

The total duration of this pulse train schedule varies according to the selection of periodic interrupt frequency, the selection of IPI or the number of stimulation channel. But when this IPI is set to 20 msec (50 Hz) and the number of stimulation channel to four, total control duration attains to about 30 sec. This is thought to be sufficient to control a sequence of one human movement, like grasping a cup and moving it to patient's mouth.

In practice, the construction of this table is done on the host computer by some convenient construction tool, and next this table is loaded to the portable unit through the interface unit, shown in figure 4.

DISCUSSION

This study is the first step to implant all elements necessary for FES control inside the patient's body, such as a computer system and some peripheral elements, various sensors and electrodes. The main purpose of this study is to clarify whether a micro processor used here can be the controller of FES, and results show that this system has efficient capacity for actual use.

More studies are intended to be continued, and an A/D converter, necessary for gathering some kind of biosignals, is intended to be equipped with this MICRO-FES system.

ACKNOWLEDGMENTS

This study was supported by the TOYOTA Found Grant No. 84-II-065 and No. 85-III-013. The authors acknowledge the active contributions of Dr. J. Kawamura, Department of Rehabilitation, Osaka Rosai Hospital, Sakai, Japan, Dr. K. Akazawa, Faculty of Engineering, Osaka University, Suita, Japan, Dr. T. Tamaki, Orthopaedic Department, Wakayama Medical College, Wakayama, Japan, Dr. K. Nishihara, Osaka Electro-Communication University, Neyagawa, Japan, Dr. K. Yoshinaga, Orthopaedic Department, Chiba University, Chiba, Japan and Mr. K. Komai, Kawamura Orthopaedic Appliances Company, Neyagawa, Japan.

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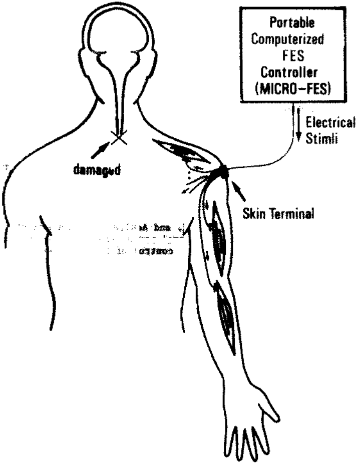

Fig. 1 – The principle of MICRO–FES system.

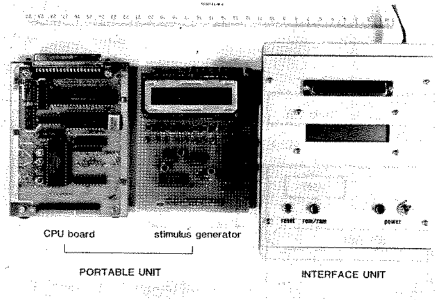

Fig. 2 - MICRO-FES system.

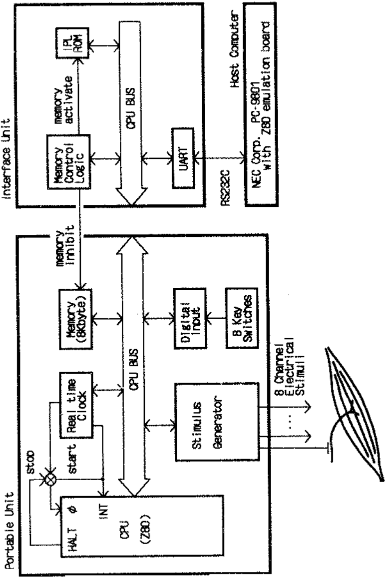

Fig. 3 - Configuration of MICRO-FES System.

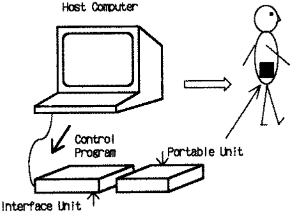

Fig. 4 - Procedure to use MICRO-FES system.

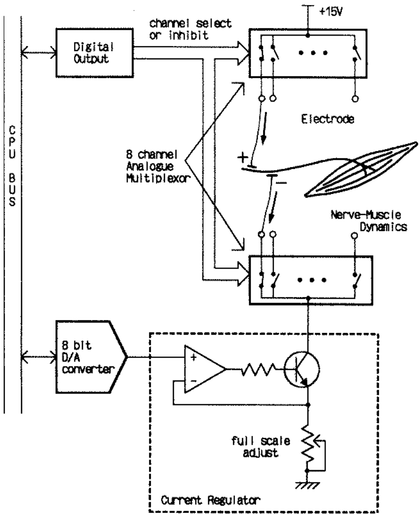

Fig. 5 - Hardware configuration of stimulus generator.

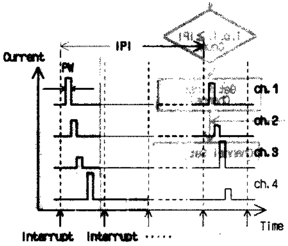

Fig. 6 - Stimulus waveform parameter definitions.

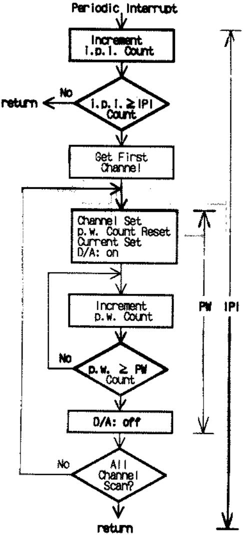

Fig. 7 - Flowchart of FES control routine.

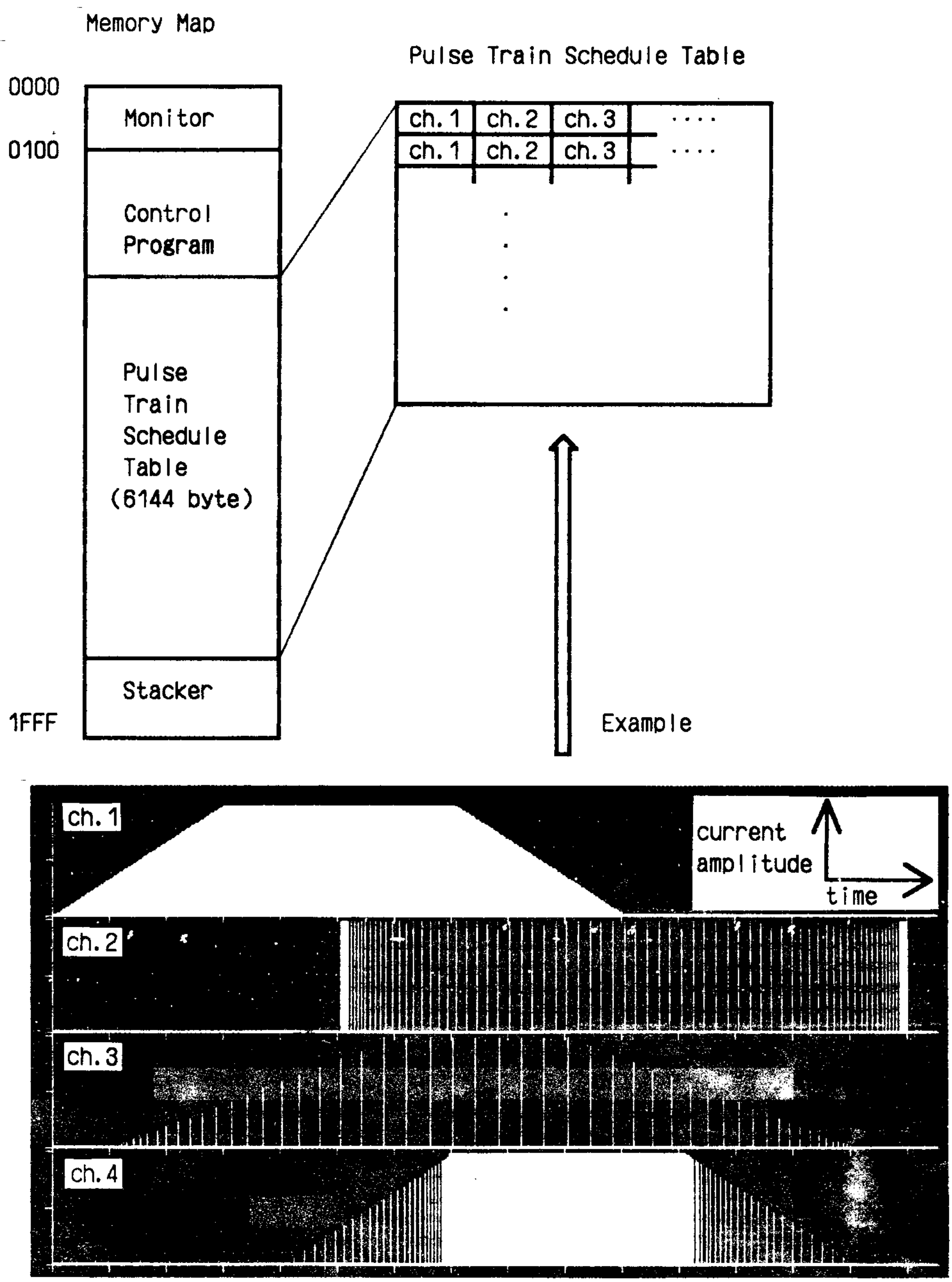

Fig. 8 - Configuration of Pulse Train Schedule and an Example.