PROGRAMMABLE MUSCLE STIMULATOR FOR ACTIVATING PARALYTIC PATIENTS

Akin Cellatoglu and Balasubramanian Karuppanan
Department of Computer Engineering
European University of Lefke
Turkish Republic of Northern Cyprus
Mersin 10, Turkey
acellatoglu@eul.edu.tr , kbala@eul.edu.tr

Sakthikanal Subramaniam
All India Institute of Medical Sciences
New Delhi, India

ABSTRACT

Defective muscles and associated nerves affect the functioning of the parts of the human body leading to paralysis. In order to provide temporal recovery from paralysis the affected muscles can be identified and stimulated in a periodic sequence by driving required electrical current intensity into the muscle. The amplitude, frequency and pulse width of the muscle current are adjusted to see the response and their values are set up in accordance with the requirements demanded by the seriousness of the muscle defect. A programmable muscle stimulator operated by a microprocessor interfaced to PC is designed to meet this requirement and is reported.

Keywords: EMG instrument, muscle stimulator, paralytic treatment, striated muscle**.**

1 INTRODUCTION

Stimulating the muscle in human body by driving electric currents is being practiced in anorectoplasty and sphincter muscle stimulation [1]-[5]. In the past, a simple electronic device that can generate the current pulse train with manually selected intensity levels was reported [6]. We now include additional features to this unit and extend this to a microcontroller which is duly interfaced to a PC as to be suitable for treating paralytic patients.

In the anatomy of every human being there are mainly eleven major muscles functioning below the hip. The microcontroller in the proposed muscle stimulator sets the amplitude, width and frequency of the electrical current pulse train for driving the required electrical energy into the defected muscle. These parameters are determined based on the seriousness of the defect in the muscle. The severity of the muscle defect is understood from the EMG instrument [7] whose electrodes are fixed with the patient during the period of stimulation. The data of the instrument are read to microprocessor and muscle current is set up accordingly.

It is to be noted that when the front muscle is contracting the back muscle is relaxing. When the muscle contracts we apply the electrical current pulse. The EMG instrument senses the time of contraction and the time of relaxation. Depending upon the extent of the data provided by the sensor the current intensity to be injected is adjusted so as to get the optimised result. Periodic treatment of the current injection helps the muscles and nerves system to recover from the defect and the patient can move his legs for some longer period of time until the defect reformulates again.

2 SYSTEM DESIGN

Fig. 1 shows simple schematic diagram of the programmable muscle stimulator. The frequency of the current pulse to be injected into muscle is generated by a Voltage Controlled Oscillator (VCO). The frequency is generated as per the command issued from microcontroller. Based on the information gathered from the EMG equipment the microcontroller also adjusts the duration of the pulses. This is realized with a Monostable Multivibrator (MSMV). The amplitude of the current pulses is adjusted by the microcontroller by tuning an ‘active R’ [8] incorporated in the voltage to current converter embedded with the current injecting probes. We need to maintain a high voltage level around 200V so as to inject the current pulses of amplitude around 200mA into the muscle. This high potential is derived from a rechargeable low DC battery cell with the DC to DC converter circuit. The display unit provides digital display of the level of the current flowing into the muscle and also some other relevant information such as time spent on stimulation and muscle contraction time.

2.1 Basic Pulse Train and Energy Level Needed

The basic form of the current wave form that is to be injected into the muscle is shown in Fig. 2 where A is the amplitude, τ is the duration of the pulsing time and T is the period of the cycle.

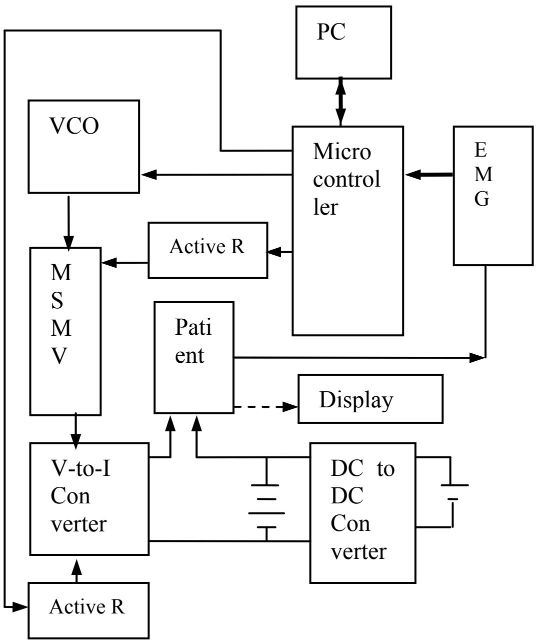

Figure 1: System Outline

Figure 2: Timing Diagram

By controlling these parameters electrical energy propagating into the muscle could be controlled.

The electrical power driven = $i^2 \cdot R$ (1)

where R is the muscle impedance realized at the probe.

$$\text{Current } i = \frac{1}{T}\int_{-\frac{\tau}{2}}^{\frac{\tau}{2}} A^2 dt \quad (2)$$

$$= A\sqrt{\frac{\tau}{T}} \quad (3)$$

Power driven

$$= A^2 \frac{\tau}{T} \quad (4)$$

Energy consumed on the muscle

$$= A^2 \frac{\tau}{T} tx \quad (5)$$

where *tx* is duration in which probes are touching the muscle.

2.2 Control of Parameters and Hardware Outline

The hardware is developed for controlling the desired parameters of electrical current needed for optimized muscle stimulation.

2.2.1 Frequency Control

The frequency is controlled by changing the voltage applied to the VCO. The circuit diagram of the VCO is shown in Fig. 3. The clock generator generates TTL compatible pulse train at a frequency of 256Hz. This frequency can be divided by a factor falling in the range of 1 to 256 conceding the range of output frequency lying in between 1Hz to 256Hz. The present analog input voltage given to the ADC determines the current frequency division factor. An 8-bit binary counter is working in association with the ADC for reaching the desired frequency division. For the given analog voltage driven, the binary word from ADC is instantaneously compared with the counter word and when a match is reached the counter is reset and simultaneously the MSMV is triggered to produce a pulse. Thus the frequency divided output from MSMV is controlled in accordance with the analog input. Referring to Fig. 1, the microcontroller provides an instantaneous binary word which is converted into analog voltage by an embedded DAC (Digital to Analog Converter) and fed to the VCO. This voltage input to VCO is set to reach a value in the desired frequency range for muscle stimulation. Recent devices [9] are fast in nature and are selected for rigging up the hardware.

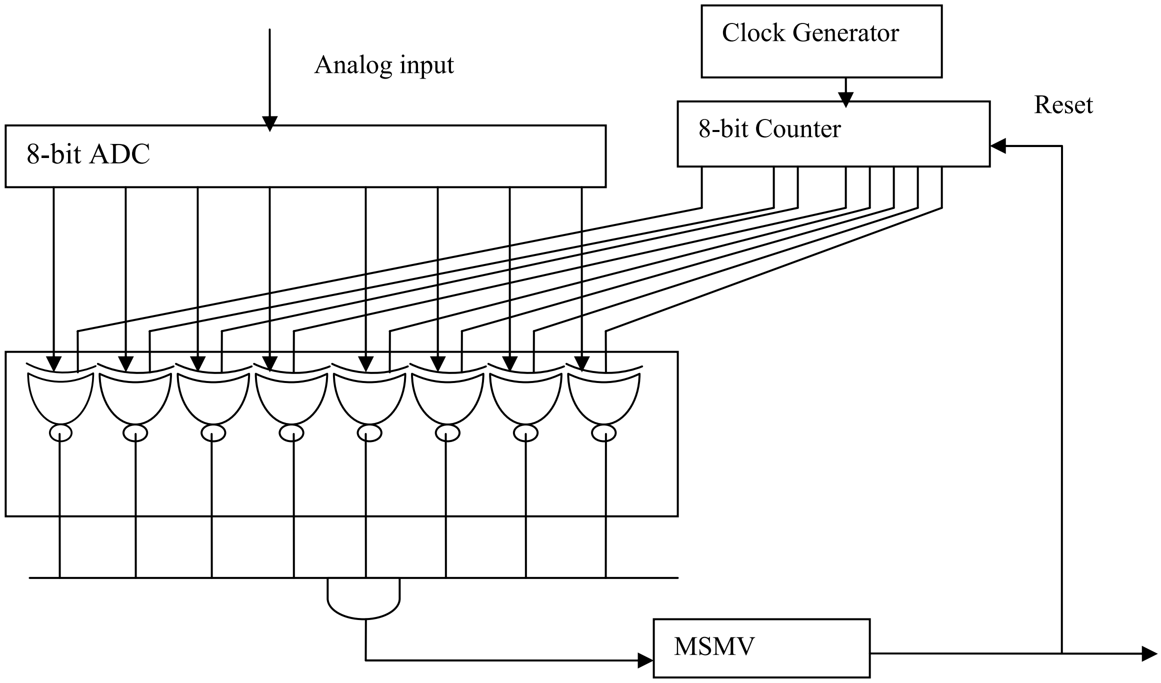

Figure 3: VCO Circuit Generating Pulse Train

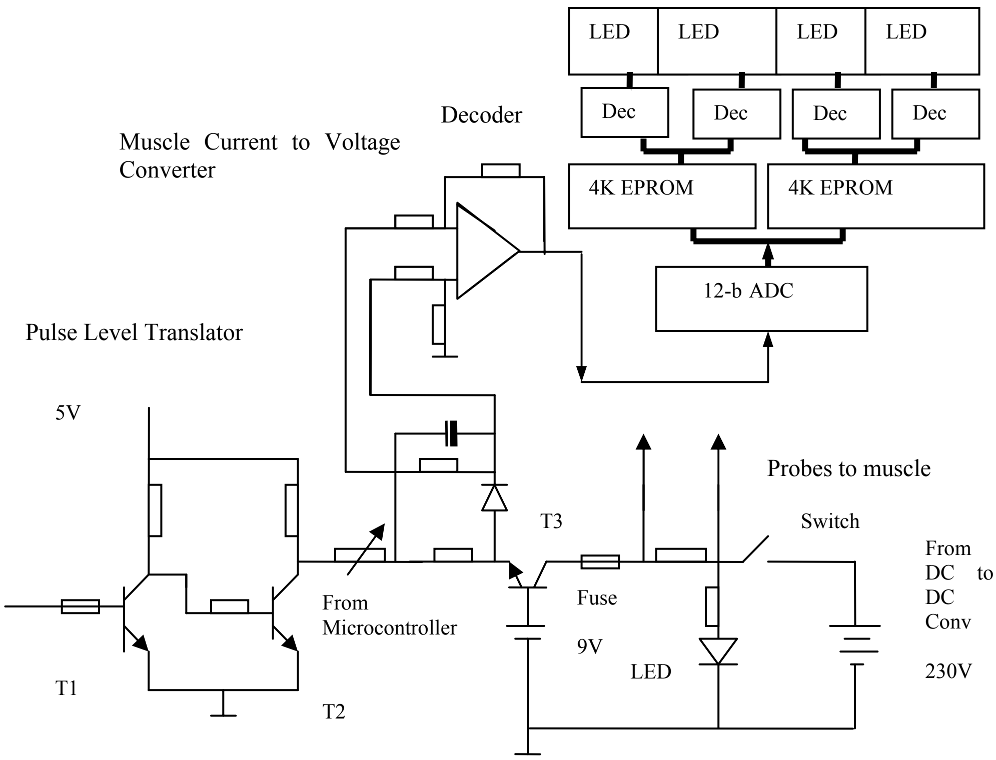

Figure 4: Muscle Drive and Display Circuit

2.2.2 Amplitude Control

The pulse train from MSMV drives a voltage to current converter (Fig. 4) as to inject the electrical current into the muscle. The level of the pulse voltage is translated and extended to common base transistor whose collector current would be dependant on the *active R* connected to emitter. This resistance is controlled from microcontroller as to decide the muscle current. Like before [8], the *active R* is realized with a FET where a fixed resistor *'r'* is connected across source to drain and the control voltage is driven to the gate. The *active R* is realized across the external drain to source resistor where the *Rds* of the FET comes in parallel with this. Fig.5 shows its principal connection.

The *active R* realized is

$$Active\ R = \frac{Rds \cdot r}{Rds + r} \qquad (6)$$

The FETs used in practice have *Rds* in the range of 100 Ohms to 100K Ohms and recent devices [9] have still larger range. The microcontroller provides the control voltage in analog form to drive the gate of the FET. After deciding the current to be driven into the muscle, as a byte of data, it is converted into equivalent analog voltage by the Digital to Analog Converter of the microcontroller before driving the gate.

The muscle current is sensed from the voltage dropped in a resistor connected in emitter circuit. This voltage is rectified, amplified and taken for display. A lookup table approach is employed to simplify the display hardware. The sensed voltage corresponding to muscle current is digitized with an ADC and addressed to EPROMs where the data for display of all possible values of analog volts are stored. Therefore, the surgeon can see the current driven into muscle in 7-segment LEDs. There is a Yellow LED (not shown in figure) which shows the muscle contraction time. When it is glowing the current will be injected into the muscle.

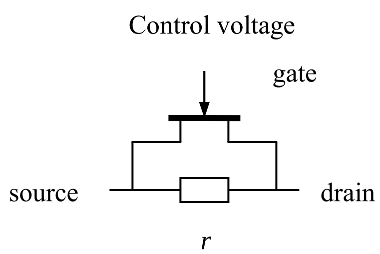

Figure 5: Principle of Realizing Active R

2.2.3 Microprocessor Outlook

The microcontroller is implemented with 8086 family of microprocessor with associated RAM, EPROM, keyboard, display, timer, interrupt interface, and I/O ports. ADCs and DACs are also included such that analog input and output are handled easily. Recent high performance 8-bit flash ADCs [10] are employed wherever needed. The Microprocessor reads the EMG signals through its port, assesses the seriousness and finds the concerned data to control the frequency, duration and amplitudes of the muscle current and drives them to respective ports. Again lookup table approach is used for reaching simplified hardware.

2.2.3.1 EMG Readout

Electromyography (EMG) is a medical procedure for measuring the responses of muscle to nervous stimulation [7]. EMG instrument detects the electrical potential generated by muscle cells when these cells contract and produces electromyogram. Electromyography can help to distinguish primary muscle conditions from muscle weakness caused by neurologic disorders including muscular dystrophy, inflammation of muscles, peripheral nerve damage, strained nerves, myasthenia gravis, amyotrophic lateral sclerosis, disc herniation, and others. The data gathered by EMG instrument are read through a port of microcontroller on time multiplexed basis.

3 SOFTWARE OUTLINE

The monitor program of the microprocessor takes care of all needs of muscle stimulation and supporting facilities. It includes main routine with several subroutines. It is developed on structured basis involving several dedicated procedures. Also, interrupt service procedures help in solving several tasks. The monitor program is loaded in EPROM and when there is updating needed it can be programmed again. When the system is reset it performs all the initialization tasks.

3.1 Main Routine

Main routine performs display routine that displays the muscle current and present time. Reads muscle current, refers the lookup table and displays the present muscle current in LEDs. Obviously when the probes do not touch the muscles the reading would be zero.

The information about muscle current flow is displayed for two seconds period and then the data concerned to display present time are accessed from relevant registers and driven to the display unit. The present time is also displayed for two seconds duration. The display operation of two seconds each for muscle current and present time is repeated cyclically.

3.2 Software Operated Digital Clock

As mentioned before, the system facilitates display of the present time and it is run by a software operated digital clock. This gives instant information to the surgeon about his commitment of time involved for stimulation activity. This is implemented in a way similar to the ones already reported [11]. Three counters called as seconds-counter, minutes-counter and hours-counter are organised as registers in memory locations and maintained by the software. A 1Hz pulse train programmed in timer associated with microprocessor interrupts the microprocessor periodically. In the interrupt service procedure the seconds counter is first incremented and its count is carried on to update the minutes-counter and hours-counter accordingly. The digital clock follows 24-hours format and arranges to display the hours and minutes with two digits each.

The presetting of the present time is performed on interrupt basis. The operation of a switch (not shown in figures) gives an interrupt to microprocessor for this adjustment. The data for seconds-counter, minutes-counter and hours-counter are reloaded in sequential steps by operating the keyboard.

3.3 Subroutines

Many subroutines called in the main routine and in the routines called by interrupts are employed in the software. One of the essential subroutine is EMG readout procedure where it initializes handshake signals needed for reading the data sequence from EMG instrument in time multiplexed basis. The readiness of the EMG equipment to provide information is tested by reading a flag and the data are gathered in sequence.

Upon reading all desired parameters of the EMG the microprocessor calls a procedure to compute the index factor as to know the severity of the muscle defect of the patient. The index factor is estimated on time average of the muscle parameters observed for a set period of time. It changes its value regularly at intervals of minutes.

To simplify the process of estimating the frequency, amplitude and pulse width of the electric current pulse train to be injected into muscle, a lookup table is employed. The address of the lookup table being of word length 12-bits, 3-bits each are reserved for three muscle parameters and another 3-bit is reserved for the index factor. This activity results in the lookup table size is of 4K locations where 16-bits data is stored in each location.

*Perform Main Routine

* Access display data and drive the display unit

* Call EMG readout Procedure

* Set the pulse train parameters

refer lookup table

and drive data to ports

• VCO port to adjust frequency

• Active R of MSMV port to

adjust pulse width

• Active R to adjust the amplitude

* Wait a while

* Jump to start

Figure 6: Operation Flow Sequence

The data word length of 16-bits of the selected address is accessed and the magnitude of three parameters are recovered on bit manipulation basis. Only the least significant 12-bits of the data are used in the process where each parameter occupies only 4-bits of size. This concedes 16 possible values of frequency, pulse width and magnitude for the electric current pulse train to be driven into the muscle. The sequence of operations performed in this task is briefly indicated in Fig. 6.

4 CONCLUSION

The programmable muscle stimulator reported here can easily be used for further applications such as in surgical operation on striated muscles. A minor change in the hardware needing the inclusion of a potentiometer operated by surgeon as to control the intensity, duration and frequency of muscle current pulse train can be included as to be operated in some desired circumstances. As the DC value of the muscle current is seen in the display by the surgeon he can raise or lower the current level by adjusting the potentiometer. A procedure in the software need be included as to read the voltage in the potentiometer and to set the current parameters accordingly.

The span of the parameters of the electrical current pulses is restricted to fall in regions having no consequences on the muscle and human nerve system. The amplitude and pulse width of the stimulating current has to be larger enough to meet the threshold of excitability of the stimulated tissue. They should not be too large to cause muscle fatigue or tissue damage. The pulse repetition frequency (PRF) governs the periodic excitation of nerve fibers and this should be kept in the desired range. While low PRF may not cause required excitation larger PRF might result in muscle fatigue. The nominal ranges of amplitude, pulse width and PRF are 5-250mA, 20-200µs and 10-60Hz respectively.

Since PC is interfaced with the microcontroller graphical display of EMG data received by microcontroller can be transferred to PC for making graphical display in the CRT monitor. The waveform of the current pulse train injected presently can also be displayed for surgeon to watch. This is additional information than the digital display of muscle current in LEDs. The clinical software involving databases of patients and doctors, diagnosis of the treatment, future observation to be made, visit details and billing information can be installed and maintained in PC.

Further facilities needed as per clinical requirements can be attempted to be incorporated in the system. For example, if breathing rate and electrocardiogram are desired to be monitored while treating the paralytic patient or doing the surgical operation it can be accommodated by incorporating appropriate sensors for picking up the signals and adapting the software to be compatible with the hardware. Furthermore, any desirable feature necessitated in the hospital environment and associated recording facilities might easily be incorporated in the system by adding the required hardware and software.

5 REFERENCES

[1] DeVries P. and A.Pena, "Posterior Sagittal Anorectoplasty", Journal of Pediatric Surgery, Vol XVII, pp. 638-643 (1982).

[2] Hedlund H. and Pena A, "Does the distal rectal Muscle in anorectal Malformations Have the Functional Properties of a Sphincter?", Journal of Pediatric Surgery, Vol XXV, pp. 985-989, (1990).

[3] Pena A. and DeVries P.A, "Posterior Sagittal Anorectoplasty: Important Technical Considerations and New Applications", Journal of Pediatric Surgery, Vol XVII, pp. 796-811 (1982)

[4] Pena A, "Surgical Management of Anorectal Malformations: A Unified Concept", Pediatric Surgery International, Vol 3, pp. 82-93 (1988).

[5] C.J Vaizey, M.A Kamm, I.C Turner, R. J Nicholls and J. Woloszko, "Effects of short term sacral nerve stimulation on anal and rectal function in patients with anal incontinence", Gut, Vol 44, pp. 407-412 (1999).

[6] K.Balasubramanian and M.Mak, "A versatile muscle stimulator", Proceedings of the IV International Symposium on Biomedical Engineering, Peniscola, Spain, pp. 216-218 (1991).

[7] M. B. I. Reaz, M. S. Hussain, F. Mohd-Yasin, "Techniques of EMG Signal Analysis: Detection, Processing, Classification and Applications", Biological Procedures Online, vol. 8, issue 1, pp. 11–35 (2006).

[8] K.Balasubramanian, "Op-amp VCO and binary FSK generator", Electronics World, Vol 104, No 1744, pp. 298-299 (1998).

[9] Texas Instruments Semiconductor, Master Selection Guide, Bedford, UK (2009).

[10] K.Balasubramanian, "On the Design and Development of Flash ADCs", Journal of AMSE-Modelling Measurement and Control, A-series, France, Vol 76, No. 5, pp. 31-43 (2003).

[11] K.Balasubramanian, "Multi-time Zoned Digital Clock", IEEE Trans on Cons. Electron, Vol 37, No 4, pp. 867-872 (1991).