Transferring Electromyogram Signal between Limbs

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***Abstract*—This paper introduces a sensing and stimulation system to transfer the electromyogram (EMG) signal from one limb to another, aiming to enable self-electro-physical therapy. The presented technique depends on sensing EMG signal from one limb muscle and, simultaneously, stimulating the corresponding muscle in the other limb by this signal. The technique has been implemented on a standalone cheap microcontroller. The sensing and stimulating circuits have been implemented using off-shelf components. The delivery of the stimulating signal has been done noninvasively through surface electrodes.**

Keywords— Electromyogram, EMG, Electrical Stimulation, Rehabilitation, Peripheral nerve injury, Electro-physical therapy

I. INTRODUCTION

Peripheral nerve injury is a serious medical condition. If a peripheral nerve is damaged then muscles stimulated by this nerve will not receive information from the brain and, therefore, they become paralyzed or weakened. Unlike the spinal-cord, peripheral nerves are capable of healing [1,2,3], this may make damaged ones require medical interventions. One of these interventions is the electro-physical therapy which is an important intervention to remediate impairments and promotes mobility functions [3].

In this paper, a technique for peripheral nerve injured persons are proposed to train their limb muscles, by themselves or under physician supervision, by using the EMG signals of their healthy muscles in the other limb. The proposed technique depends on sensing and acquiring the EMG signal from the healthy limb by surface electrodes, pre-processing, and simultaneously transferring it to the other limb to stimulate the corresponding muscles. This aims at transferring the movement form the healthy part to the impaired one.

The rest of the paper is organized as follows. Section II explains the EMG sensing technique. Muscles stimulation process is explained in Section III. The integration of the EMG signal sensing and muscles stimulation is contained in Section IV followed by the conclusion in Section V.

II. SENSING MUSCLE'S SIGNAL

When a person desires to move a limb, neural signals from the brain travel down passing through the spinal cord to the peripheral nerve fibers. These neural signals, in form of electrical impulses, synapse onto target muscle fibers responsible for controlling the limb. These electrical impulses cause the muscle to contract. Tendons attach muscles to the bone. Therefore, when the muscle contracts, the tendon pulls on the bone and a movement occurs [4]. The action potential is the mechanism responsible for muscle contraction. The EMG is a summation of all action potentials occurring in a muscle at a same time [4]. Noninvasive surface electrodes placed on the skin above a muscle can detect the EMG signal. Fig. 1 shows a schematic diagram of the proposed system for transferring EMG from one limb to another.

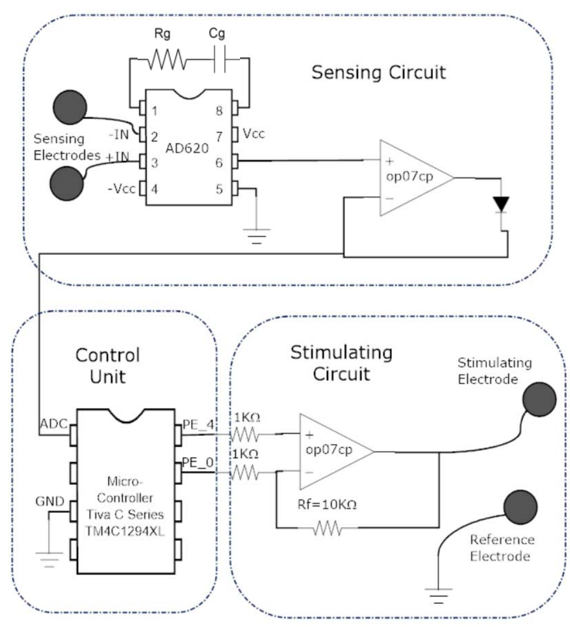

Fig. 1. Schematic diagram for the system of sensing and stimulating EMG signal in muscles

Some simple procedures should be done before placing the surface electrodes on the skin to insure the good conduction. The surface of the skin should be cleaned with alcohol prior to electrode attachment, then a conductive gel is used to decrease the skin impedance. As illustrated in Fig. 2, to acquire differential EMG signals, two electrodes, about 2-3cm apart (one inch) above the required muscle, e.g. biceps or forearm, are attached and one electrode is attached to the bony part of the elbow to serve as a reference or ground electrode [4,5,6].

The EMG signal is very weak differential signal so, it is required to be handled by an instrumentation amplifier. AD620 amplifier is used in our system. It is a low cost, low noise, low power, low input bias current, and high accuracy instrumentation amplifier which makes it well suited for medical applications [5,7].

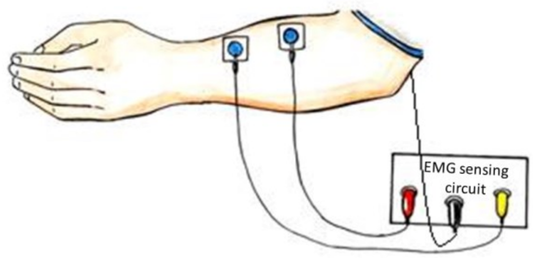

Fig. 2. Placing EMG sensing electrodes on the muscle

The red, black and yellow leads, in Fig. 2, are connected to the +IN, -IN and reference pins of the AD620, respectively, that shown in Fig. 1. The gain "G" is adjusted using external resistor R_G to get a suitable amplified output EMG signal [7]. It is given by

$$R_G = \frac{49.4k\Omega}{G-1} \quad (1)$$

To decrease the problem of the large DC offset of the EMG signal, a capacitor C_G is connected in series with R_G to form complex impedance Z_G [8]. The gain then depends on both R_G and C_G. Also the gain becomes frequency-dependent. The frequency-dependent gain is given by

$$G = \frac{49.4 * 10^3}{|Z_G|} + 1, \quad (2)$$

Where

$$|Z_G| = \sqrt{R_G^2 + (\frac{1}{\omega C_G})^2} \quad (3)$$

Thus, the gain is composed of all pass and high pass gain. It increases with the increase of the signal frequency. The DC gain is 1.

By selecting R_G= 47Ω and C_G= 470μF, the maximum gain≈ 1050. An exemplar EMG waveform at the output pin, while making a muscle contraction, displayed by the oscilloscope is shown in Fig. 3. It is clear that the signal is a cumulative sum of many action potential signals. Signal processing can be done on this signal to extract useful information and eliminate artifacts and interferences. For example, signal processing can provide information about the relative speed of limbs' movement by extracting the frequency content and do some calibrations on it [9]. The amplitude of the EMG signal reflects the force exerted by the muscle in the movement. The simplest utilization of the sensed EMG signal is to identify the presence/absence of the movement in the muscle.

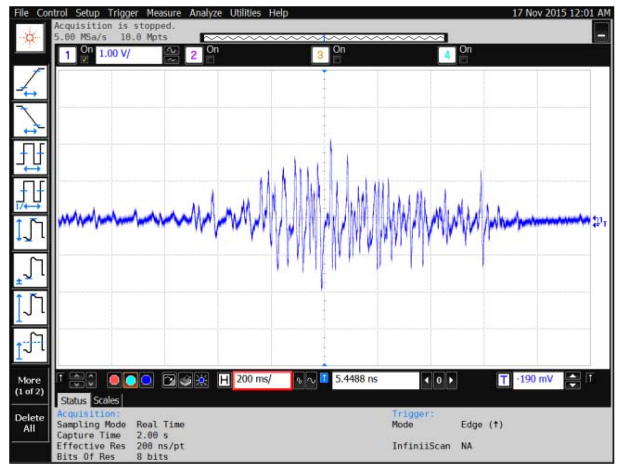

Fig. 3. EMG signal sensed from the biceps muscle displayed by Agilent Digital Oscilloscope

III. STIMULATING MUSCLES

Electrical muscle stimulation is applying a small electrical pulses to paralyzed muscles to restore or improve their function. The frequency of the stimulation signal is in range between 30 and 35Hz [10]. This frequency can be changed slightly by increasing or decreasing the time between pluses to make muscles contract slower or faster, respectively. Symmetrical or asymmetrical biphasic rectangular impulses must be used to be comfort and unpainful. In addition, biphasic impulses are used to decrease the risk of chemical burns at the electrodes. As shown in Fig. 4(a), the pulses time has not to exceed the range between 350 and 450 μs [10]. Impulse trains are constructed with long work "on time". The “off time” between each train, must be double, triple or quintuple the “on time”, because the paretic muscles need greater time for recovery as shown in Fig. 4(b).

Stimulating a muscle needs two electrodes only, one for the stimulating signal and the other is used as a reference electrode. The two electrodes have to be 2~3cm apart (one inch) above the muscle to be stimulated.

The circuit used to generate the stimulating signal simply consists of an operational amplifier (Op-Amp op07cp) used in differential input mode with feedback resistor R_f= 10KΩ, and

1KΩ input resistance as shown in Fig. 1. The noninverting input of it is connected to the output pin PE_4 of the microcontroller (In this work, Tiva C Series, TM4C1294XL has been used [11]) while the noninverting input is connected to the output pin PE_0. The stimulation signal is obtained by composing the signals of PE_0 and PE_4 through the differential amplifier. The signal on PE_4 is high for 450 µs then low for the next 30mS and, similarly, the signal on PE_0 but shifted for 450µs. So, the resulting signal is biphasic square wave with duration 900µs. The gain is about 10 to 11 and the output signal from the microcontroller is 3.3V, so the op-amp always goes to saturation giving either the maximum Vcc or minimum -Vcc. Typically, the amplitude of the stimulating signals starts to take effect after it exceeds ±7 volts (14V peak to peak), and this amplitude may differ and become larger depending on the skin impedance and the quality of the contact between stimulating electrodes and the body's surface [10]. Increasing pulses' amplitude controls the force of contraction in the stimulated muscles.

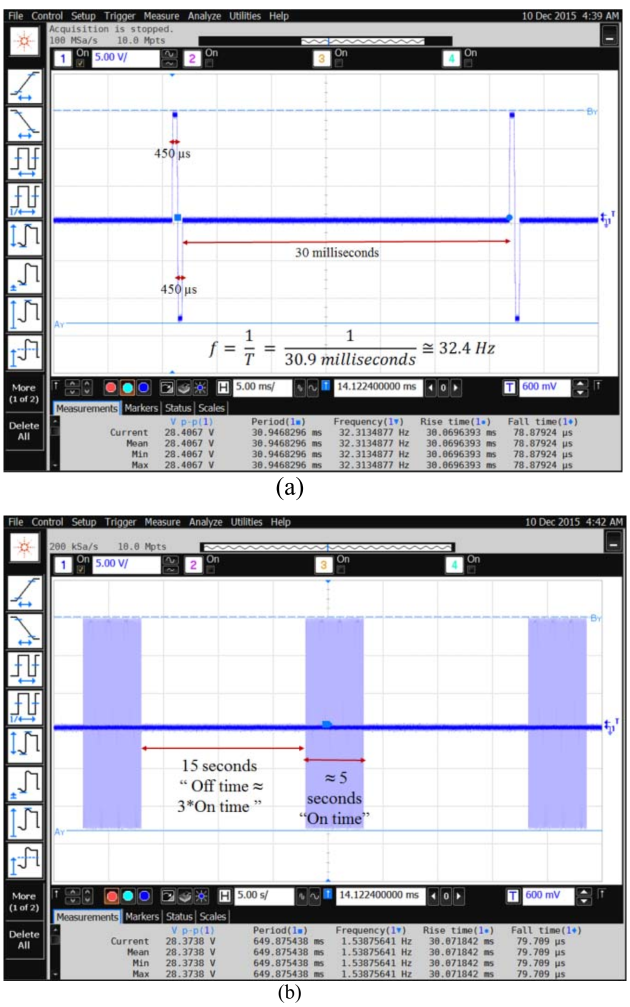

Fig. 4. Stimulating signal. (a) Electrical stimulating pluses' period and duration. (b) On time and off time for stimulating signal

IV. Transferring signal between two Limbs

After sensing the EMG signal from the source limb, a stimulating signal can be delivered to the corresponding muscle in the other limb for the same person or even another person. If a different person, then, an additional electrode is needed to connect both persons to the same reference [12]. Fig. 5 shows the experimental setup of the system.

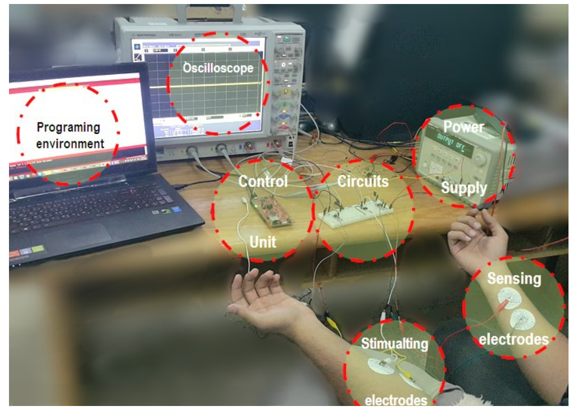

Fig. 5. Practical testing of the system

The EMG signal shown in Fig. 3 is biphasic signal, but microcontroller's ADC accepts analog input between 0 and 3.3 volts only. The EMG signal has to be rectified before entering to the ADC's pin. Super diode circuit, as an active rectifier consists of op-amp and diode, is a simple way to solve this problem as shown in Fig. 1. The output is the positive part of the EMG signal with minimum voltage drop.

Making a threshold level to compare with the coming rectified signal to the ADC's pin gives information about the existence of muscle movement, but in sometimes threshold level may make mistakes in taking decision due to the accumulation of DC charge on the input signal. In this case, taking a number of samples e.g. 128 samples from the ADC and storing the max and min value of them, then subtracting "Difference value = max value – min value" is a more accurate threshold for detecting the existence of muscle's movement. If the signal detected refers to muscle movement, the microcontroller sends out a stimulating signal to the output pins to stimulate the target muscle at the same time. Also, some modifications on the stimulating pulses can be done to simulate the original movement in speed and force, by recognizing EMG signal power and frequency and change the stimulating pulses' frequency and amplitude according to it. This complete process is shown in Fig. 6.

V. Conclusion

A system of transferring EMG signal between limbs to be used in electro-physical therapy has been introduced. In this system, the EMG signal acquired from the source limb has been preprocessed to get a better identification for the sensed signal. The system has been implemented and tested using cheap off-shelf components. An extension of this work can be done by increasing the number of sensing and stimulating sensors. Thus the processing unit of the system can be modified to extract several features of the sensed EMG signal to transfer and control several specific motions between the source and target limbs.

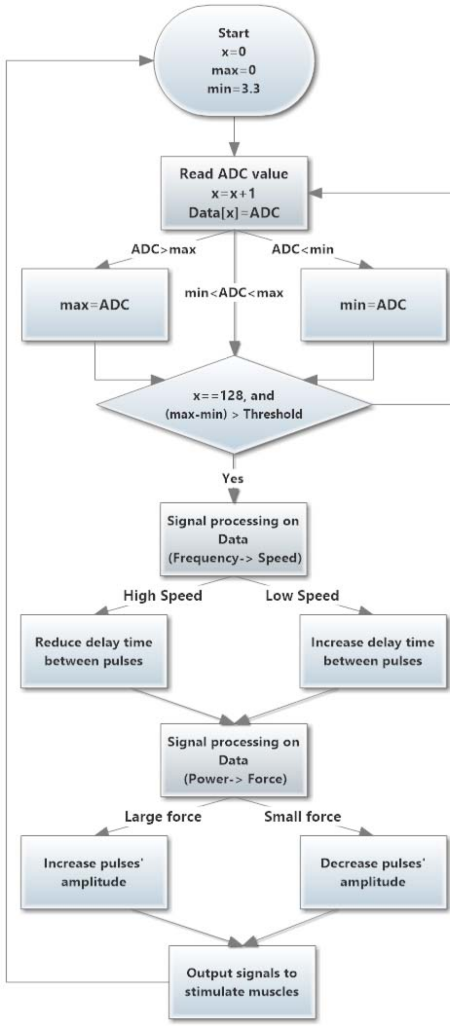

Fig. 6. Flow chart showing the process flow in the microcontroller

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