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Development of EMG Sensor for Prosthetic Hand Control

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Abstract—*Electromyography (EMG) signal can be used for many applications like diagnosis of neuromuscular diseases and control of prosthetic devices. EMG signal is well recognized as an effective tool to generate control commands for prosthetic devices and human-assisting manipulators. The residual EMG signal from remaining part of missing arm can be used to restore the capabilities of hand amputees through myoelectric prosthesis. Single channel, highly sensitive EMG Sensor was developed in this work to pick up the myoelectric signal non-invasively using surface electrodes. The acquired EMG signal on LabVIEW Platform was further processed and converted to Pulse-width modulated (PWM) signal to drive the servomotor coupled with 3-D printed prosthetic hand. Proportional control strategy was successfully implemented for basic open and close movements of fingers in order to grab various objects.*

Keywords*: Electromyography; Pulse Width Modulation; Data Acquisition; LabVIEW.*

1. INTRODUCTION

Electromyography (EMG) is a technique which deals with the measurement of electrical signals generated by activation/movement of muscles (i.e. contraction and relaxation).These electrical signals are called EMG or myoelectric signal. Electromyography is a very useful method in measuring muscle stimulation that has numerous applications in the diagnosis and treatment of diseases as well as the potential to enhance human abilities [1].The EMG signal's amplitude lies in between 1-10 mV, making it a considerably weak signal. These signal lies in the frequency range from 0-500 Hz and most dominant in between 10-350 Hz.EMG signals are recorded by two methods which are invasive and non-invasive. In invasive method, needle electrodes are used to measure EMG signal. But non-invasive is often preferred, because it is directly placed above the skin surface without inserting electrodes into patient body which makes it safe and easy to use.

Amputation is the removal of a limb by trauma, medical illness, or surgery. In the upper limb a transhumeral amputation refers to a severing of the arm above the elbow, distal to the shoulder, while a transradial amputation refers to a severing below the elbow. Prosthetics are devices that substitute a missing or defective part of the body. This paper focuses prosthetic device for transradial amputee. On the basis of functionality there are three types of upper limb prosthetics. The first is a cosmetic prosthetics which is for appearance purpose only. The second type is a body powered prosthetics, which use the wearer's body power to operate. The main disadvantage to such type of prosthetics is that they require an unnatural movement in order to operate them to perform a task. The third type is externally powered prosthetics which are powered by external power source and different type of bioelectrical signals (like EMG, EEG and ECOG) for controlling .In myoelectric prosthetics, EMG signal produced by the residual limb is used to control prosthetic device. In this, surface electrodes are placed on the skin of the residual limb to pick up the EMG signal. This type of prosthetic can often allow the user multiple degrees of freedom (DOF), meaning multiple movements can often be made simultaneously and within a smooth succession [2].

There are basically two types of myoelectric control systems; pattern recognition and non-pattern recognition based system. In pattern recognition based control systems the input signals are converted into output commands using features. Moreover features can be categorized into - time domain, frequency domain and time-frequency domain [3]. Time domain features are the most commonly used features in prosthesis control. Depending on these features the segments are classified into different tasks using a classifier and those tasks are used to control prosthesis [4][10]. Non-pattern recognition control systems do not use classification. Some of the non-pattern recognition control methods are proportional control, onset analysis, and threshold Control. In proportional control, speed or torque of a prosthetic joint is determined to be proportional to the amplitude of EMG signals [5][6]. Non-pattern recognition control algorithms are simple to implement compared to pattern recognition based control algorithms, but the number of functions that can be controlled is limited [8]. Behavior of non-pattern recognition control systems depends on characteristics of the data acquisition system, anatomy and physiology of muscles, position of sensors on the skin and muscle fatigue [7]. It is most effective to use non-pattern recognition methods alongside pattern recognition control systems.

This paper mainly focuses on the development of EMG sensor to drive prosthetic (3-D printed) hand using proportional control strategy to aid transradial amputee. This includes sensor design with various stages, and acquisition of EMG signals on LabVIEW platform using Data Acquisition device (DAQ). The acquired signals are then processed on LabView real time environment to control width of PWM signals. These PWM signals are then used to drive the servomotor coupled with prosthetic device. Fig. 1 shows the schematic of prosthetic hand control using EMG signal.

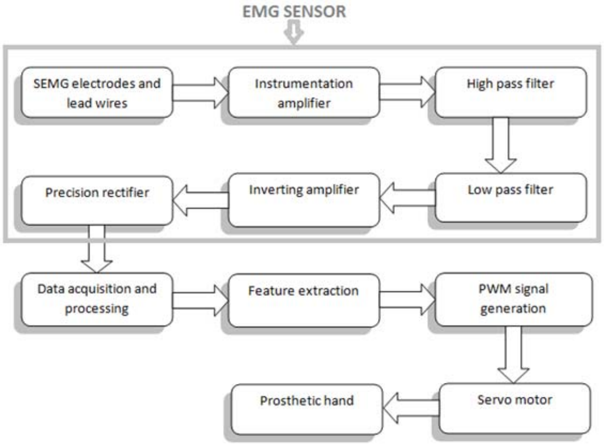


Fig. 1.1. Schematic of prosthetic hand control using EMG signal

2. DEVELOPMENT OF EMG SENSOR

a. EMG Surface Electrode with lead wires-

Electrodes are transducers which converts ionic current to electronic current. Electrodes secured on the skin are able to provide a crude assessment of the muscle activity below. Here three surface type electrodes were used to pick up EMG signal, two of these electrodes are often placed on the target muscle, while the third is meant to ground the signal and is often attached on or near a bone in order to implement the differential configuration. For accurate measurement of EMG signal, proper placements of electrodes are must. Here to mimic the natural hand movement, myoelectric signals are picked by placing electrodes on flexor Carpi radialis, extensor Carpi radialis longus and the reference electrode on wrist since these muscle groups are directly responsible for the palm and wrist movements of interest.

These disposable surface electrodes are connected to sensor through lead wires. The lengths of the lead wires are adjusted as per the need. Shielded cables were used as lead wires to prevent EMG signal from electrical interferences. 3.5mm jack and socket assembly was used to connect sensor and lead wires which minimizes the noises due to motion artifacts.

b. Preamplifier-

An EMG signal picked by surface electrode has amplitude in micro volts therefore a preamplifier stage is must in the first stage of EMG sensor to amplify micro level EMG signal (100µV) into milli voltage (mV). Instrumentation Amplifier INA128P IC with high CMRR, high input impedance was used as pre-amplifier whose gain is adjustable as per equation(1).

$$G = 1 + \frac{50K\Omega}{R_g} \qquad (1)$$

Where, R_g is variable resistor to adjust gain of instrumentation amplifier.

Because of the weak amplitude of the EMG signal, the difference in the amplitude between some useful EMG signal components and the noises can be very small. If the gain of the pre-amplifier is set too large, the noises will be simultaneously amplified enormously, thus leading to the instability and saturation of the subsequent amplifier. To avoid such a consequence, the gain of the pre-amplifier is preferred to be set around 10[9]. Here the gain of preamplifier is adjusted to 11.4.

c. High Pass and Low Pass Filter-

After doing the sufficient amplification in the first stage the signal is passed through a filtering circuit. The reason to use filter is that the noises and the EMG signals are simultaneously amplified, which is undesired. Second order sallen key active high pass filter with cutoff frequency 10Hz and pass band gain of 2 was used in order to remove motion artifacts and external noise components from EMG signal. To design a filter, the corner frequency, the roll-off rate, and the circuit topology have to be selected as per the need. The corner frequency and the pass band gain of the second-order Sallen-Key high-pass filter are given by equation (2) and (3) respectively [11].

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \qquad (2)$$

$$G_{pass} = 1 + \frac{R_4}{R_3} \qquad (3)$$

Where f_c is the corner frequency and G_{pass} is the pass band gain.

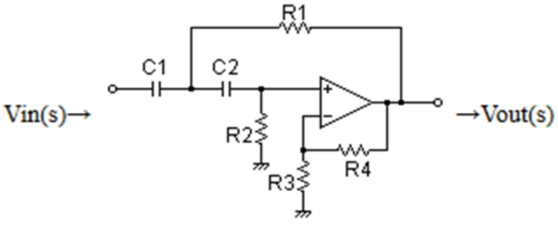


Fig. 2.1. Second order sallen key active high pass filter

Smoothen EMG signals are required at the processing stage which is done using the active low pass filter [11]. Since the noises coupled into the circuitry from electromagnetic radiation are mainly in the high frequency band, therefore a second-order sallen key active low pass filter was used here with a corner frequency of 350Hz and pass band gain of 1.59.The corner frequency and the pass band gain can also be calculated using equation (3) and (4) the same way as for high-pass filter design.

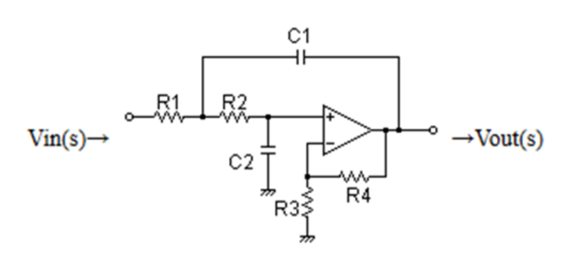


Fig. 2.2. Second order sallen key active low pass filter

d. Amplifier(second stage amplification)-

Since the Amplitude of EMG signal lies in the range of µV to low mV therefore it is necessary that the gain of the amplifiers used in EMG applications must be range from 1000 to 10000. Consequently, the amplification process commonly incorporates several stages. The final stage of the EMG sensor is the inverting amplifier with very high gain around 200 to further amplify the EMG signal such that it can be easily acquired with sufficient amplitude. Overall gain of all the stages of sensor was achieved around 7000.

e. Precision rectifier -

Since In this work, the precision rectifier is used rather than the normal rectifier because 0.7V forward bias voltage drop of diode affect the EMG signal across it. Normally, the EMG signal will be fluctuating in the range between positive and negative value during the muscle movement. But, this project requires smooth signal to drive servo motor which is achieved by using precision rectifier. There are several type of rectification that can be done. But ,in this case, a full wave rectifier is used because EMG signals will contain both positive and negative signals, if half wave rectifier is used some of the information of this signal might be removed.

3. EMG SIGNAL ACQUISITION AND PROCESSING

Using the developed sensor, EMG signal was acquired on LabVIEW platform with NI DAQ interface. LabVIEW, which is the abbreviation for the Laboratory Virtual Instrumentation Engineering Workbench, is a platform and development environment for a graphical programming language developed by National Instruments. It has been widely used for signal analysis in many applications. Acquired signal was further smoothen and its RMS value was extracted to control the duty cycle of the PWM signal.

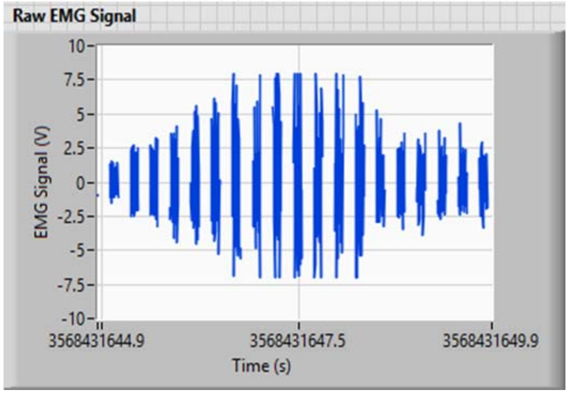


Fig. 3.1. Acquired EMG signal

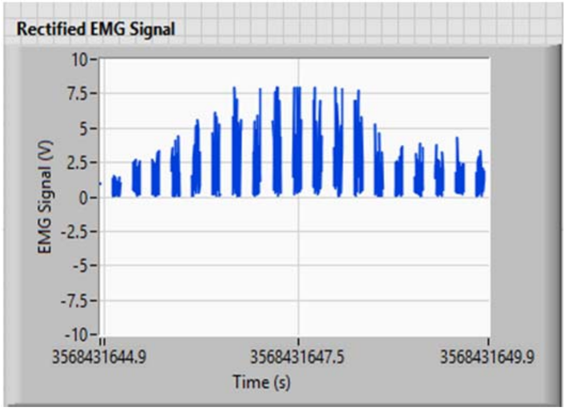


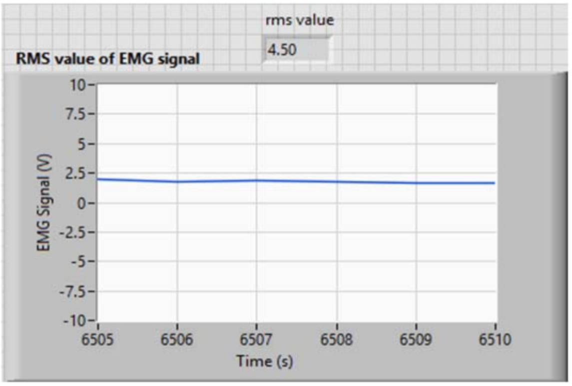
Fig. 3.2. Rectified EMG signal

4. GENERATING PWM SIGNAL USING ACQUIRED EMG SIGNAL

The rms value of the acquired EMG signal was used to control the width of the PWM signal. The RMS represents the square root of the average power of the EMG signal for a given period of time.RMS value of EMG signal is related to constant force and non-fatigue contraction of the muscle.

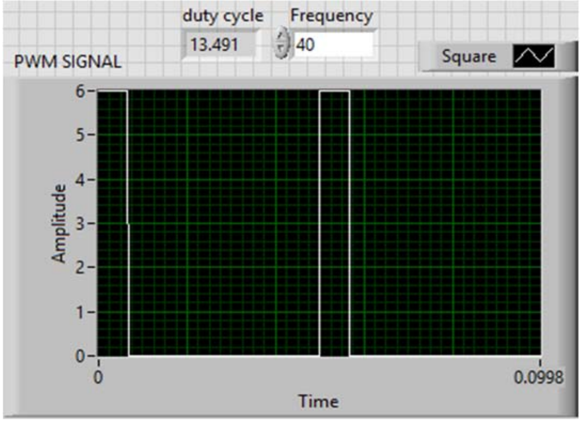
A PWM signal is a periodic square wave signal with two possible amplitudes 0V and 5V. The two parameters of PWM that can be modified are the frequency of the signal and the duty cycle - the percentage of each cycle where the signal is high. In this case the frequency was fixed, duty cycle was altered which alters the pulse width.

PWM signal was generated using fixed amplitude and frequency whereas rms value of EMG signal was used to control the duty cycle.



rms value: 4.50

Fig. 4.1. RMS value of EMG signal



duty cycle: 13.491

Frequency: 40

Square

Fig. 4.2. Generated PWM signal

5. IMPLEMENTATION OF PROPORTIONAL CONTROL STRATEGY TO DRIVE PROSTHETIC HAND

In this work non-pattern recognition based proportional control strategy was implemented to move the fingers of 3d printed hand coupled with servomotor. Strength of EMG signal was used to control the width of PWM signal accordingly to run servomotor which drives prosthetic hand.

A servomotor is a rotary actuator that allows for precise control of angular position .It consists of a motor coupled to a sensor for a position feedback. It also has a servo drive to complete the system, this drive uses the feedback sensor to precisely control the rotary position of the motor, and this is called closed-loop operation. The angle of displacement of servo is controlled by Pulse Width Modulation. MG-995 metal gear servomotor was used in this work which provides maximum torque up to 10kgf.cm.

Proportional opening and closing of five fingers of 3d printed hand was achieved as per the intensity of EMG signal. The prosthetic hand was able to grab various objects to fulfill basic needs of transradial amputee.

6. CONCLUSION

The developed sensor was able to acquire EMG signal from fore arm muscles to drive the fingers of prosthetic hand. The proportional control scheme was implemented and tested successfully in a 3d printed hand prototype with three degrees of freedom and one actuator, driven by EMG signal. Basic Open and close movement of fingers was performed as per the strength of EMG signal in order to grab various objects.

Fig. 6.1. Developed EMG sensor with electrodes and lead wires

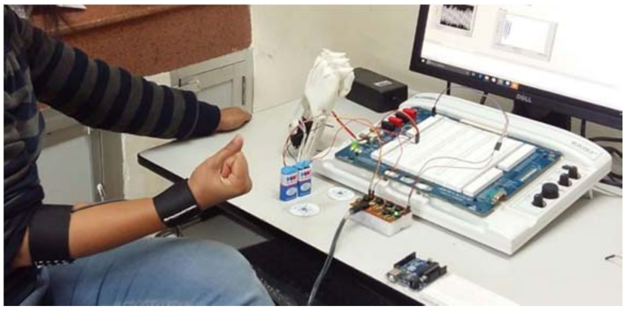


Fig. 6.2. Controlling 3D printed hand with EMG signal

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