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EMG Signal Analysis and Application for Arm Exoskeleton Control.

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***Abstract*—Aim of this paper is to throw light on the concept of electromyography (EMG) signals and how they can be applied to real world applications through the employment of motion support exoskeleton.**

The scope of the present research is to design a low power, low cost EMG based exoskeleton system and its experimental implementation in an elbow joint, naturally controlled by the human. Preamplifier section is designed with operational amplifier OPA4227 through which raw EMG signal is extracted by passive electrodes. Amplified EMG signal is passed through filter section for restriction of frequency range. This restricted signal is rectified to acquire constant polarity for higher average output voltage. Acquisition and processing of EMG signal is done by ATMEGA 32U4 microcontroller. Data is transmitted to computer for visualization through Zigbee module. Surface EMG amplitude and the torque about elbow joint construct the system design.

Keywords—Arm, Electromyography, EMG, Exoskeleton, Muscle, EMG-torque relationship, Biomedical signal noise considerations.

I. INTRODUCTION

A. *EMG signal*

The EMG signal is basically a biomedical signal which measures electrical currents generated in the muscles. These currents are generated during the contraction of muscles representing neuromuscular activities. This neuromuscular activity is the result of a signal generated in the brain which is transmitted through the nervous system to the motor neuron attached to the muscle fibers in the muscle. A depolarization wave is generated throughout the muscle fiber when motor neuron fires which creates an action potential in the muscle fibers resulting in the movement of electric charges. This electrical activity produces an electric signal in the muscle called as Electromyogram (EMG) signal.

This raw EMG signal consists of a series of spikes whose amplitude depends on the amount of force delivered by the biceps. Stronger the contraction of the muscle, larger the amplitude of the EMG signal. Also, the frequency of spikes is the firing rate of motor neurons. As the amplitude of the EMG signal is directly related to the force exerted by the muscle, it is used to determine the force signal sent to the exoskeleton.

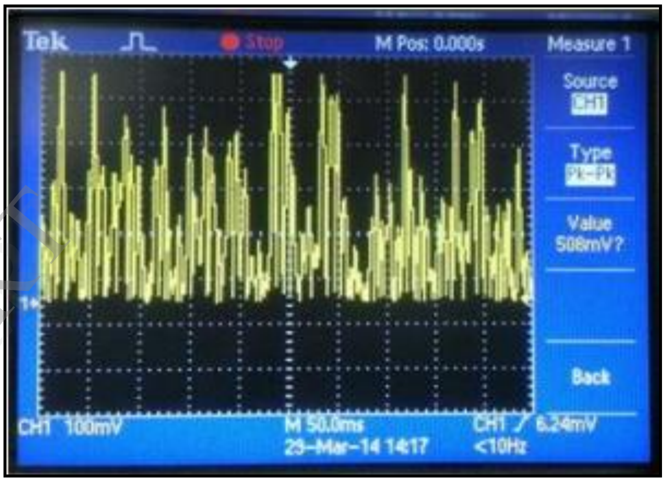

Fig. 1. EMG Signal

B. *Surface EMG*

Various types of techniques for obtaining the EMG signal are available. Clinically the use of needle electrodes is suggested however they are invasive techniques and hence impractical and uncomfortable for a portable application such as general amplitude measurement for exoskeleton control. Hence the use of surface electrodes is applied for this purpose. The most obvious advantage is the ease of application, no need of medical supervision due to its non-invasive nature and good accuracy achievable with proper precaution. The amplitude, time and frequency domain properties of the surface EMG signal are dependent on factors such as:

- The timing and intensity of muscle contraction.
- The distance of the electrode from the active muscle area.
- The properties of the overlying tissue (e.g. thickness of overlying skin and adipose tissue).
- The electrode and amplifier properties.
- The quality of contact between the electrode and the skin.

C. *Relation between EMG signal and muscle torque*

The relation between surface EMG and torque makes EMG an attractive alternative to direct muscle tension measurements. The complexity of the EMG signal origin has been a barrier for developing a quantitative description of this relation.

There are many applications that the tension exerted by the muscle group during the various activities is useful, however direct measurements are unnatural, invasive and expensive. A relation between EMG and torque simplifies the situation, because EMG is readily obtained by surface electrodes.

Studies of the relationship between surface EMG and torque have found that there exist both linear and non-linear relationships. The degree of linearity is dependent on the muscle being investigated. Characteristics of the muscle of interest may also influence the EMG to torque relationship. Muscles of uniform fiber composition exhibit a linear relationship while a random non-uniform composition of fibers behave more nonlinearly. Furthermore, the muscles display nonlinear behavior at lower torque levels due to selective recruitment of motor units at different distances from the electrodes.

As a summary, the concept of torque for the skeletal muscles is derived from the motion of the bones about a joint due to muscle contractions. Since surface EMG signal measures the activity of the skeletal muscles, a mathematical relationship can be established between the EMG amplitude and net joint torque.

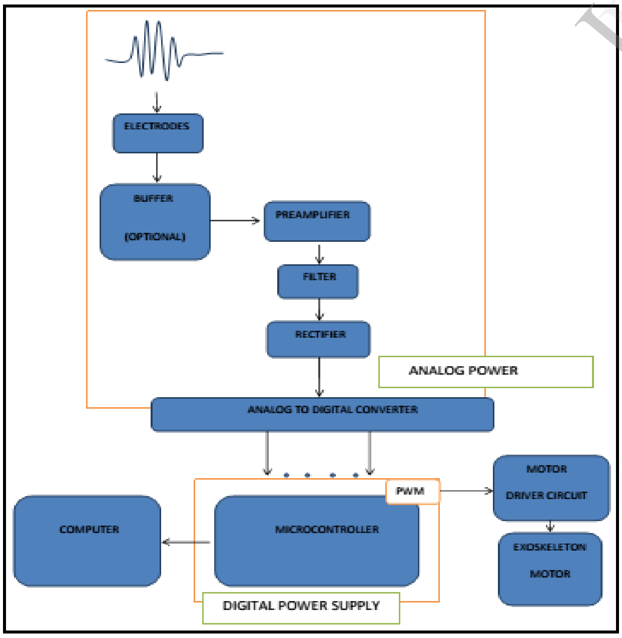

Fig 2. System Block Diagram

D. *Exoskeleton*

An exoskeleton is an external skeleton which supports a body. This exoskeleton takes its controlling signal from the EMG signals present in biceps muscle. The amplitude of the EMG signal is proportional to the amount of force delivered by the biceps. From this amplitude we can obtain the force delivered by the biceps and translate it into the torque. The torque can then be sent to the exoskeleton actuator – the servo motor. Thus an exoskeleton assists in bearing a load on the human arm. It also provides the needed support in lifting movement of the arm and to the other muscles as well. The main aim of developing this exoskeleton is to provide a structure in aiding the physiotherapy and muscle rehabilitation of an individual.

II. ANALOG INSTRUMENTATION

The methods to detect the EMG signal are varied and are increasing day by day to provide an efficient and accurate measurement system. Once the signal is captured perfectly the next big task is to preserve its originality and properties. Digital processing is the bright future wherein the signal integrity is maintained or even enhanced at times. But the signal can be escalated if it is amplified and filtered right after it is extracted through analog instrumentation and then presented for further processing.

A. *Electrodes*

The types of measuring EMG signals are categorized as intramuscular and surface EMG. Intramuscular EMG is obtained using needle electrodes and is very important to study the behavior of a particular muscle. On the other hand, surface EMG (sEMG) presents a way to extract the signal when you are concerned only with the properties (i.e. amplitude, frequency, etc.) of the signal and its applications.

The electrodes used are passive bar electrodes by Olimex. The electrodes are non-disposable and hence used right from the testing stage through debugging to the final experimentation. You can create your own set of active electrodes by placing the preamplifier close to the detection surface. This ensures that the signal is less contaminated by noise since it has to travel less thus maximizing its fidelity.

Skin preparation stage should not be ill-considered as it provides with a set of problems after a time being. Things need to be set perfect right from the start. Often you lose the signal either because the skin impedance isn't what it needs to be or the placement of electrodes is incorrect or they are misplaced due to motion of the body. Hence the skin needs to be cleaned with alcohol and should not be sweaty. The quality of the EMG signal directly depends on the quality of the electrodes, nature of the detection surface, amplifier design and its efficient digital representation.

B. *Pre-amplifier*

Since the raw EMG signal is of the order of a few millivolts it can be easily wiped out by a greater degree of noise. Thus the basic aim is to maximize the amplitude of the signal by reducing the amplitude of noise. One important property is the signal to noise ratio that denotes the dominance of noise over the EMG signal.

A set of two differential electrodes and a reference electrode is used. Differential amplification ensures that only the signal concerned is amplified while the signal appearing common to both the inputs like noise is cancelled. The instants at which the EMG signal appears at both the inputs of the amplifier are different as the signal propagates under the skin. Hence this proves that though we are measuring the same EMG signal, but by subtracting the signals captured by differential electrodes does not cancel the overall signal. The property of the amplifier to amplify only differential signal and cancel all the common signals is called Common Mode Rejection Ratio (CMRR).

A reference electrode is required to provide a common reference to the system. The signals that are measured by the differential electrodes are with respect to the reference electrode. Hence the reference electrode is normally placed on a bony part of the body. If not used the signal is largely contaminated by noise and at times has a varying offset which means the system does not have a common reference.

The choice of components and amplifier IC is crucial. Components should be precise to serve the best of their purpose. Precision resistors of tolerance ±0.1% are used specifically for the preamplifier stage. An instrumentation amplifier is built using Texas Instruments precision OPA4227 IC. It provides CMRR of up to 135dB. An integrator or the low pass filter in the feedback loop of the output amplifier is used to reduce the DC offset and AC offset present at a particular frequency. Along with CMRR the other important to look out for is low noise. The amplifier must have low internal noise and be less susceptible to surrounding noises. The sources of noise are the mains supply noise and electro-magnetic interference by other electronic devices. Radiated EMI was observed when the system was tested in a laboratory full of electronic instruments. Hence to reduce this radiated EMI a shielded cable is used through which the raw EMG signal is supplied to the circuitry.

To decide on the gain factor is again an issue that should be of utmost importance. The gain should not be so high that it amplifies some of the noise and not so low that the EMG signal is not visible as well as measurable. The signal was tested with different gain settings. Finally the signal was best viewed with a gain of 201. Remember that the gain can be greater than 201, but then it also increases the amplitude of noise. The best way to amplify any signal is in two stages. The next amplifier stage is after the filters where the high frequency harmonics and interfering low frequency signals are filtered out. Thus this greatly reduces the contribution of noise in the captured signal which then can be amplified further.

Fig. 3. Ananlog Board

C. Filters

The FFT of the EMG signal was observed on the DSO. It was found that most of the signal's energy lies between 10-500Hz. The peak of the energy spectrum is at around 60Hz that extends up to 500Hz. But the amplitude of the signal reduces considerably after 200Hz. Since we are concerned only with the peak amplitude of the signal to apply it to an exoskeleton, the filter limits are from 10Hz-200Hz. Note that for extensive study of muscle responses, the entire energy spectrum needs to be considered.

The filters are designed keeping in view the ISEK (International Society of Electrophysiology and Kinesiology) standards. 4^{th} order low pass and high pass filters are built using Butterworth approximation.

The order is chosen so as to have a steeper response with high roll off rate that brings it closer to the ideal response. Butterworth has maximally a flat response in the pass band and is the simplest to design. The design takes into consideration the "Quality Factor" and the "Damping ratio" which is determined by the capacitor ratio. The damping ratio is the factor that decides how early the sinusoidal oscillations die from their peak to zero level. Avoid the use of notch filter, because it not only reduces the 50/60Hz noise but also the signal adjoining to it. Loss of information in return of reduction of noise is not a good deal. Since the EMG signal has its peak in the 60Hz range, notch filtering is strictly not recommended. We are interested only in the positive peaks; hence full wave rectification is employed. Since the EMG signal is minuscule and of the order of a few millivolts, a precision rectifier is used to curtail the voltage drop across the diodes. A high input impedance precision rectifier is used because it gave better results than a normal

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precision rectifier in terms of equal peaks in both the cycles of AC.

The filters attenuate the signal while discarding the undesired frequencies. Thus the signal is amplified with a gain factor of 2. All the OPAMP ICs that are used were chosen such that they fulfill the basic requirements of low noise, low offset, high CMRR and high slew rate to minimize the noise and increase the desired response of the system.

III. DIGITAL IMPLEMENTATION

To communicate with the computer and the controller, the analog EMG signal must be converted to its equivalent digital signal. In order to efficiently represent the analog signal and to avoid any loss of information due to aliasing, the sampling frequency of the ADC must satisfy the Nyquist criteria. The ADC used in this case is an on-chip ADC of Atmel's ATmega32U4 controller. It has a 10bit resolution which gives satisfactory digital representation and sampling rate of up to 15ksps. An internal voltage reference of 2.56V is used that gives a resolution of 2.5mV.

Good PCB design guidelines recommend having separate supplies for the analog and the digital parts of the whole system. Thus, preamplifier, filters, rectifier and ADC are powered by an analog supply while the controller is powered by a digital supply. Both the supplies have separate grounds which are connected together at a common point.

Now we have to control the motion of the exoskeleton through a servo motor. The servo motor is an assembly of four things: a normal DC motor, a gear reduction unit, a position-sensing device and a control circuit. The function of the servo is to receive a control signal that represents a desired output position of the servo shaft, and apply power to its DC motor until its shaft turns to that position. It uses the position-sensing device to determine the rotational position of the shaft, so it knows which way the motor must turn to move the shaft to the commanded position. The servo has a 3 wire connection: power, ground, and control. The control signal is generally a PWM signal.

Servo motor used is VS-11 by Vigor Precision Ltd. Its standard direction of rotation is counter-clockwise and it requires a pulse of width lying between 800µs to 2200µs. It has a minimum torque bearing capacity of 15kgf.cm at 4.8V operating voltage and 19kgf.cm at 6V. The most important factor is that it weighs only 100 grams which makes it quite portable and comfortable to mount it on the exoskeleton.

The function of the controller is to generate a PWM signal corresponding to the digital output of ADC that will be given to a servo motor. The best way to control the motor movement is by a PWM signal. A pulse modulated signal is of a specified frequency, but the on and off times of the pulse can be varied according to our requirements. The ON time of the pulse decides how much power must be delivered to the motor which in turn decides the rotation of the servo.

Fig. 4. Digital Board

III. LabVIEW

The real time signal is displayed using LabVIEW software. LabVIEW is a comprehensive development environment that provides engineers and scientists unprecedented hardware integration and wide-ranging compatibility. LabVIEW's VISA module is used. VISA is a standard I/O language for instrumentation programming. VISA is a high-level API that calls into lower level drivers. VISA is capable of controlling VXI, GPIB, or Serial instruments and makes the appropriate driver calls depending on the type of instrument being used. Thus, VISA provides interface independence. This can make it easy to switch interfaces.

Here, VISA module is used to input the digital data from the controller serially. Array is used to take each digital value once at a time, which is then divided by 255 and multiplied by 0.65 to convert it to an analog value. This analog value is then plotted as a waveform for EMG signal representation.

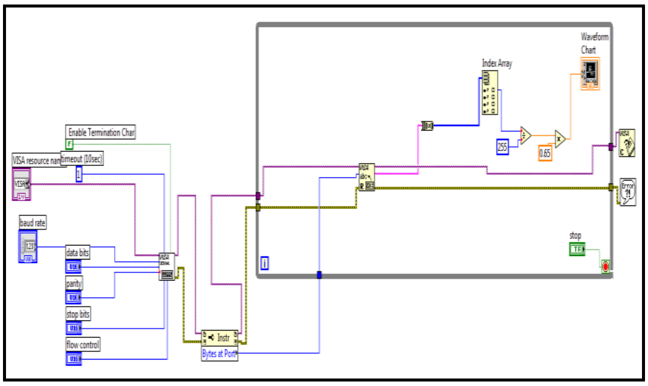

Fig. 5. LabVIEW

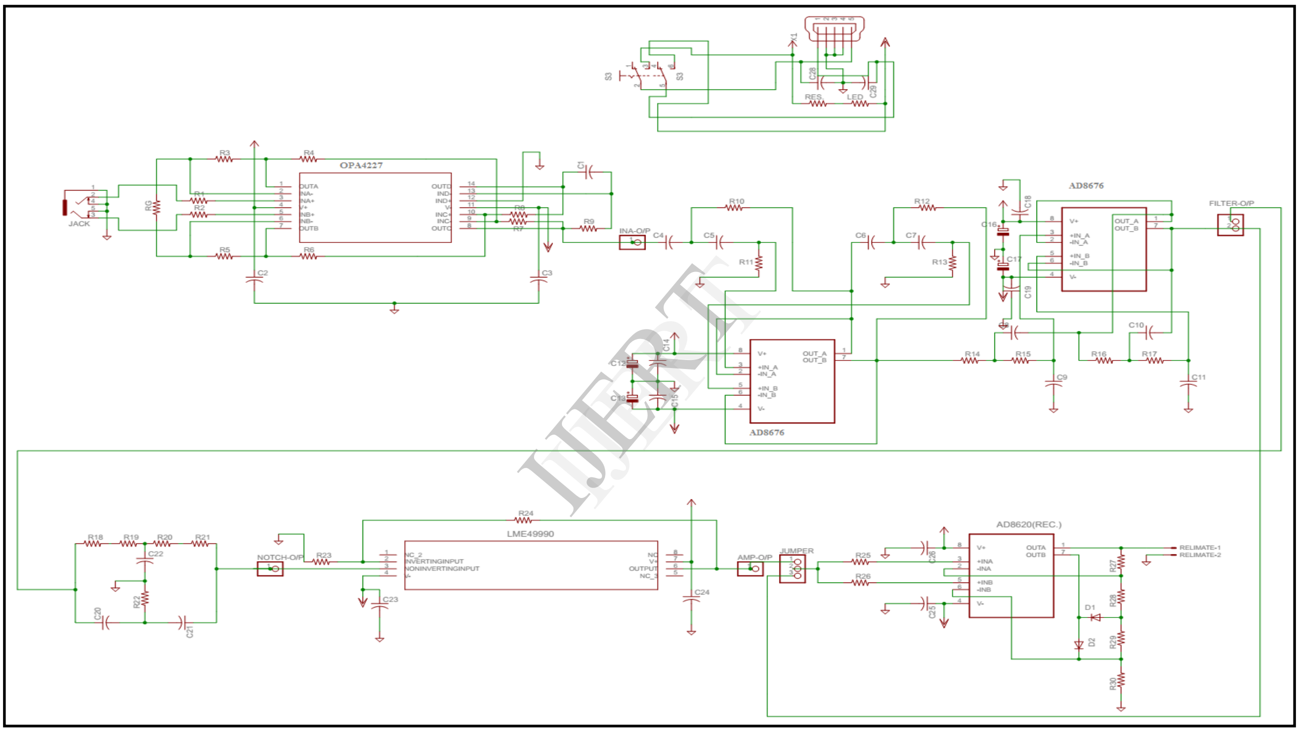

Fig. 6. Analog Schematic

IV. NOISE CONSIDERATIONS

The ambient noise plays an important role in measuring EMG signal. Noise originates from different sources of electromagnetic radiations such as electrical power wires, fluorescent lamps, light bulbs, radio and television transmission, etc. The surfaces of our bodies are constantly inundated with electromagnetic radiations and it is virtually impossible to avoid exposure to it. Hence the quality of electrodes and amplifier design must be given special attention.

There are two main sources of motion artifact: one from the interface between the detection surface of the electrode and the skin, the other from movement of the cable connecting the electrode to the amplifier. Both of these sources can be essentially reduced by proper design of the electronic circuitry. Thus double sided PCB with gold plating is used with high end design.

Factors affecting the EMG signal are categorized into following:

- Instability of signal: EMG signal amplitude is random in nature. The signal is affected by the firing rate of the motor units, which mostly fire in the frequency range of 0-20Hz. Thus filters are designed for 10-200Hz.
- Electrode structure and placement: Larger electrodes are susceptible to interference from

adjacent muscles. In this case, the electrode size and the inter-electrode distance must be reduced in order to capture only the desired EMG signal.

- ECG artifacts: ECG bursts may contaminate the EMG signals whenever measured near the heart. This artifact can be reduced by good skin preparation and proper positioning of ground electrode.

The signal-to-noise ratio (SNR) is an important factor which can be greatly increased by accurate design of the instrumentation amplifier. The input impedance of the amplifier must be very high in order to match the skin impedance. The CMRR is the first specification to be considered. Thus, OPA4227 is used for instrumentation amplifier design with CMRR of 135db which reduce the common mode noise and amplify the required EMG signal.

V. APPLICATIONS

A. Computer interface for signal monitoring

With the current technology, computer provides the best interface between any system and the human user. Similarly, the EMG signal can be reproduced graphically to the user or physician undertaking the EMG measurement using a Graphical User Interface (GUI) over many simulation and measurement tools available. Here, LabVIEW GUI has been used for the graphical representation of the EMG signal as a function of time to the user. Furthermore additional analysis and digital filtering can be achieved using LabVIEW program to enhance the details and understand the intricate nature of the EMG signal as it varies along time and under various test conditions.

B. Exoskeleton for muscle rehabilitation support

In physiotherapy often external exoskeleton structure is employed to help exercise and rehabilitate an injured muscle. An active exoskeleton not only provides support but also operates on the EMG signal amplitude thus providing actual response of the recovery of the patient as well as providing unsupervised exercise for physiotherapy.

VII. CONCLUSION

The study of EMG signal has been a topic of discussion which has gained quick attention. Extracting and analyzing the signal are the important tasks to be carried out. We presented in this paper how to extract EMG signal to get accurate information and the noise reduction techniques to be considered while designing the system. Many EMG testing and measurement systems available in the market are quite expensive. Cost effective systems if built and applied to exoskeleton can help greatly in the field of rehabilitation.

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