# Design of an Arm Exoskeleton Controlled by the EMG Signal

Mark Novak
Cornel College PHY312
December 2011
Professor Derin Sherman

## Introduction

An exoskeleton is a supporting structure on the outside of a body. The name stems from the words exterior and skeleton. In the context of this project, it is an exterior support structure of the human arm amplifying the force delivered by the biceps brachii. The actuator of the exoskeleton taking the place of the biceps is a DC motor acting on the elbow joint of the exoskeleton. The design of this exoskeleton takes its controlling signal from electrical signals in the biceps muscle. This electrical signal, called the Electromyogram (EMG), is a measure of the electrical activity in the biceps. The amplitude of this EMG signal is directly related to the amount of force delivered by the biceps. From this amplitude we can make a close determination of the force delivered by the biceps and translate this force into the torque which can then be sent to the exoskeleton actuator – the DC motor. In this manner, the exoskeleton will assist in bearing a load on the human arm.

## The Controller of the Exoskeleton – the EMG Signal.

The EMG signal is a measure of the electrical activity of the muscle. The electrical 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. The motor neuron fires resulting in a depolarization/repolarization wave throughout the muscle fiber. This wave 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 which can be picked up by well-placed electrodes on the surface of the skin. The acquired signal is called the 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 – the stronger the contraction of the muscle, the larger the amplitude of the EMG signal. The frequency of the spikes is the firing rate of the motor neurons. Since 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. Figure 1 is an example of the EMG signal during a contraction of the biceps brachii.
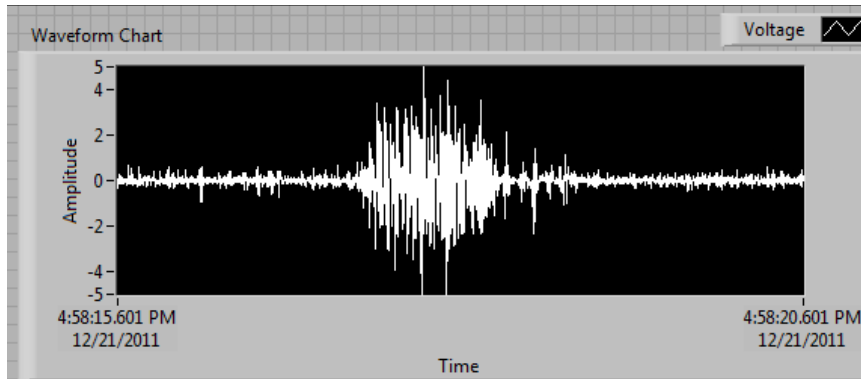
Figure 1. The EMG signal of a contraction of the biceps brachii.

## Three Stages of the Project
There are three stages to my project. The first is accurate pickup of the EMG signal with electrodes and an analog circuit. The second is computer processing of the signal which translates the EMG signal into signals which control the exoskeleton. The final stage is sending the translated signal to the actuator of the exoskeleton and construction of the exoskeleton.

## I.    Pickup of the EMG Signal
Correct pickup of the EMG signal requires five steps including electrodes and an analog circuit with four integrated circuits (ICs).

1. The EMG signal is acquired using three electrodes. Two are placed on the biceps muscle while the third is placed on a bony part of the arm to serve as a reference or ground for our pickup circuit. The ideal location for the muscle electrodes is in the center of the muscle approximately 1cm apart. The reference electrode is placed on the bony part underneath of the elbow below the joint. See Figure **2**


Figure 2. Correct placement of the electrodes.

2. The signals acquired by the electrodes are fed into an AD22 Instrumentation amplifier via wires. The purpose of this step is to subtract all voltage common to both inputs. Due to the nature of the electrodes they pick up all signals in the body resulting in a very noisy signal. The only signal not common to both electrodes is the action potentials passing underneath them at different times. In Figure 3 it is possible to see that the output of the instrumentation amp is only the difference between the input signals after it subtracts the noise common to both inputs.
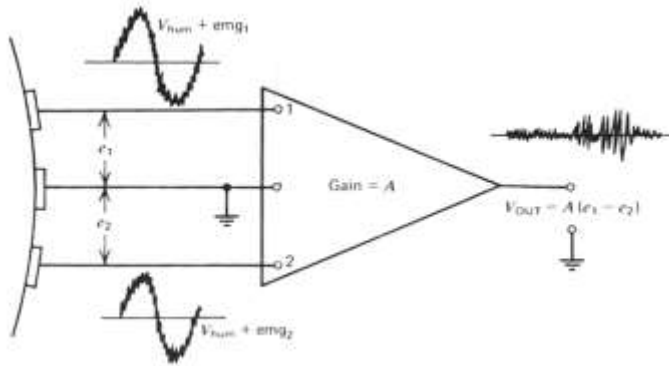
Figure 3.   Winter (1990)

   It is necessary to use an instrumentation amp with a Common Mode Rejection Ration (CMRR) of around 110dB as this 110dB reduction of common voltage greatly enhances the quality of your signal.  It is also necessary to amplify the collected EMG signal as it is from 0 -30mV.  In this IC an amplification of 100 is used to put the signal in the 0-3V range.

3. The output of the instrumentation amp is sent to a high pass filter to remove all low frequencies. The LN412 operational amp is used for this IC.  The majority of the EMG signal ranges in frequency from 20Hz -500Hz so a high-pass Bessel filter was designed with a cutoff frequency of 20Hz attenuating all lower frequencies. It is necessary to remove all contribution from <20Hz frequencies to reduce the most common corruptions of your signal – movements of electrodes and wires as well as DC bias.  The movement of an electrode on your skin can create a significant difference in the voltage it reads creating a large output from the instrumentation amp.  However, these frequencies are less than 20Hz and their contribution to the signal can be attenuated.  DC is 0Hz so it is easily filtered out.

4. This next step of the analog circuit is preparation of the signal for computer processing. As it is a common problem when using a Digital to Analog Converter (DAC) to alias high frequencies back to low frequencies (a problem arising when the rate at which DAC samples the frequency is less than the frequency itself causing the DAC to miss the peaks of the incoming frequency catching every other one and "aliasing" this high frequency back to a low frequency) a low-pass Bessel filter is included with a cutoff frequency of 500Hz to solve this aliasing problem.  The low-pass filter attenuates all frequencies above 500Hz.  Figure 4 illustrates the inputted signal by the DAC if its sampling rate is less than the signal's frequency.
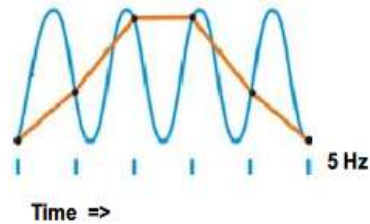
Fig.18: The effect of A/D sampling frequency on a digitized signal. Too low frequencies (lower traces) result in significant loss of signal information

Figure 4. Aliasing

5. The final necessary step of the analog circuit is to include an amplifier using the AD622 which provides a strong, clean signal for the computer to process as some noise will creep into the signal during input to the computer. If the EMG signal is strong the noise can easily be filtered out with computer filters. Figure 5 is the schematic of the entire circuit EMG pickup circuit.
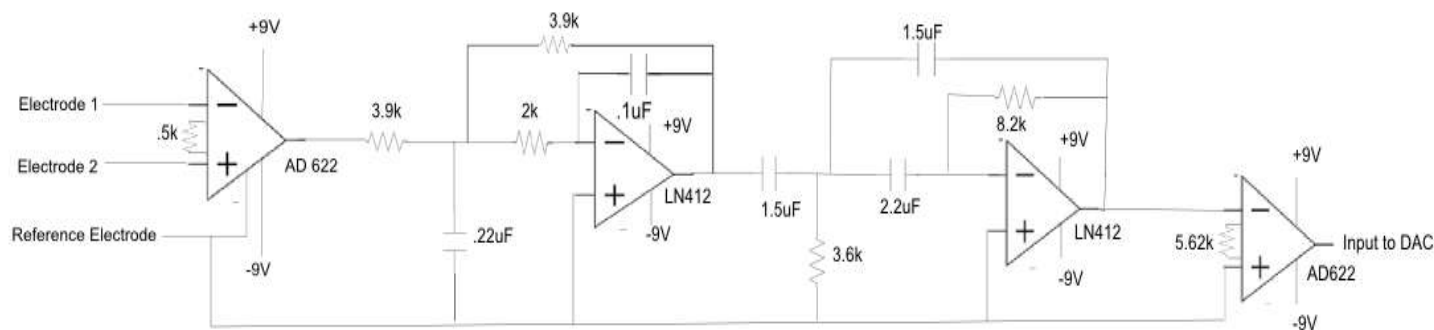


Figure 5. Schematic of my EMG pickup circuit.

## II. Computer Processing

This stage processes the EMG signal and interprets its information into translated signals which are used to control the exoskeleton. For this stage LabView from National Instruments is used. The EMG signal is inputted from the DAC to the LabView program using a DAQ assist Express VI and then filtered with a low-pass filter to remove the DC bias that comes into the signal from the computer. It is then filtered again with a band-stop filter with a band-stop of 59 to 61 Hz (it is not recommended to do this as much of the EMG signal's information is in this range, but we are really only interested in the amplitude of the EMG signal so it is fine to sacrifice a little bit of info and remove a lot of 60Hz noise to greatly increase the clarity of the EMG signal). In order to send a DC voltage to the actuator of the exoskeleton it is necessary to convert the EMG signal which is in AC to DC. The best method for doing this is by taking the Root Mean Square of a window of data points. This takes a window of data points squares them, adds them, divides by the number of data points

and then takes the square root of this number outputting a nice average DC voltage from the EMG signal.

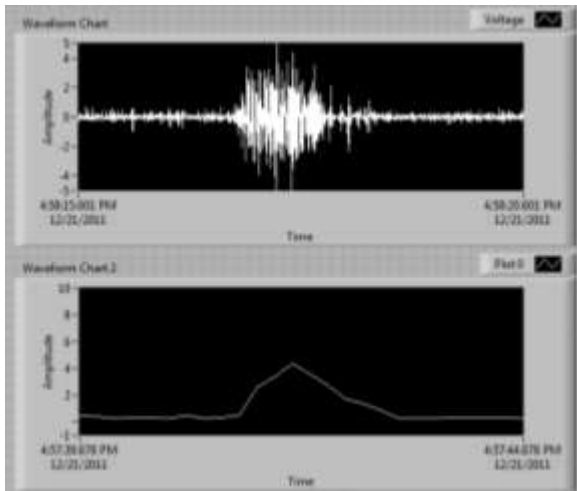$$RMS = \sqrt{\frac{1}{n}\sum_{n} x^2(t)}$$

Figure 6.  RMS formula



Figure 7. An illustration of the raw EMG signal and the processed RMS value of the signal.

Finally, the RMS value must be converted to a signal controlling the exoskeleton actuator.  From experimentation it can be determined what RMS value of the EMG signal corresponds to the force exerted by the bicep on its lever arm.  As seen in Figure 5 the RMS value of the EMG signal is linearly related to the mass in the hand which determines the force exerted by the biceps.
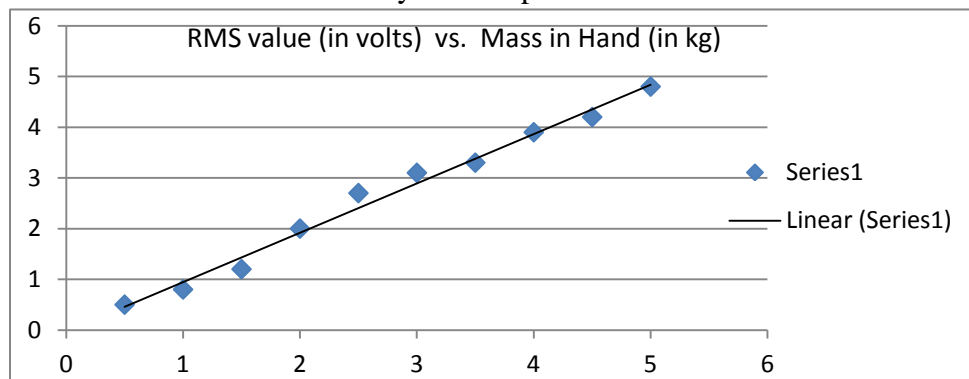


Figure 8.  Linear relation of the EMG amplitude to force exerted by the biceps.

Once we have this collected data we correlate the RMS value with the amount of torque we give our actuator. This is really just force, which is experimentally determined from the RMS value, times the lever arm of the biceps - .04m. From this value of torque we send a signal out of the computer program to the exoskeleton creating the correct output of torque in the motor, but this is stage three. Figure 9 is the LabView program which processes and translates the EMG signal into a pulse-width-modulated signal controlling the output power of the motor.
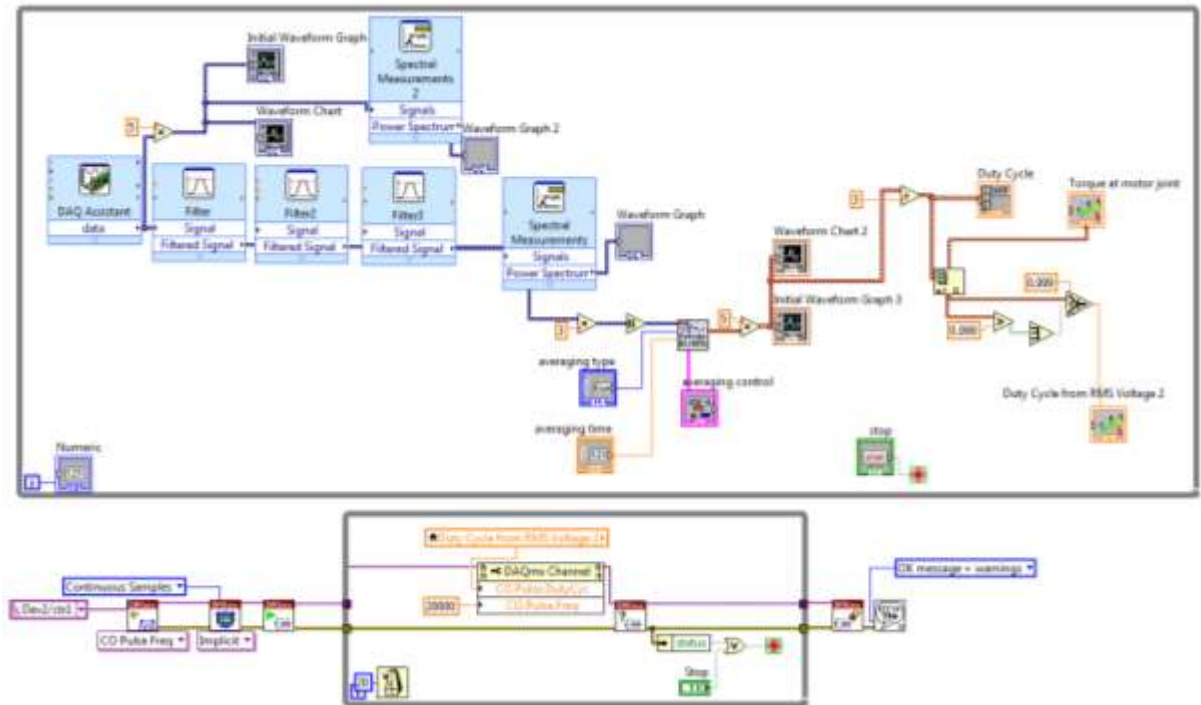


Figure 9. Labview program which processes the EMG signal and controls the motor.

### III.    Construction and Control of the Exoskeleton Arm.

1. **Control**. Having experimentally calculated the correct torque from the RMS value, the program controls the exoskeleton actuator using pulse-width modulation. A pulse-width-modulated signal is one in which the signal changes from high to low voltage at a specified frequency with the length of the high voltage being the pulse width. The percentage of the wavelength which consists of the high pulse is called the duty cycle. Increasing the duty cycle of the output signal increases the power that the motor receives. An addition to the processing program is written which outputs a pulse-width-modulated signal to an output in the DAQ which is then sent to the actuator of the exoskeleton. The DAC does not have enough current to run a motor so it is necessary to use an IRF640 Power Mosfet with a sufficient power supply to power the motor. Sending the pulse-width-modulated signal to the gate of the Mosfet controls how much current flows from

the drain to the source pins.  Finally, the power received by the motor is controlled by connecting the motor from the power supply to the drain pin of the Mosfet.

2. **Construction.**



Figure 10.  The exoskeleton of my left arm with one degree of freedom.

In designing and building the exoskeleton, proper consideration must be given to the type of motor and gearing used in the construction.  It is easiest to control a DC motor whose output torque depends on the amount of voltage received.  Therefore, a DC motor is used as the actuator of the exoskeleton.  Also, it is necessary to have the least mechanical resistance from the gearing to rotational movement of human arm because it is essential that the when the biceps are relaxed and the arm is thus falling to a straight position, that the exoskeleton follow the human arm with the arm feeling minimal resistance to its natural movement. Due to their minimal mechanical resistance, a combination of bevel and spur gears is used with a combined gear ratio of 35:1 to transfer power from the DC motor mounted on the upper arm support of the exoskeleton into rotational movement of the forearm support.   As seen in Figure 10 the motor's shaft is at a 90 degree angle to the axis of rotation of the forearm support so the bevel gears are used to change the axis of rotation of the motor to the axis of the rotation of the forearm support as well as provide a gear ratio of 4:1.  The spur gears were used to provide a larger gear ratio of 9:1 which increased the overall torque of the motor by roughly 35:1.  The gears are secured to their shafts by means of drilled and tapped holes which run through the hub of the gear into the shaft itself.  This provided a very strong, secure attachment for the gears to the shafts.  The shafts themselves are secured in the same way to the exoskeleton's upper and lower

supports.  For the first set of gears the shaft was secured into a bearing which was secured to the upper arm support and provided unimpaired rotation of the large bevel gear and small spur gear.  The larger spur gear's shaft was directly secured to the forearm support as its rotation determines the forearm support's rotation.  The upper arm support is secured to the forearm support solely by passing the shaft in the larger spur gear through a hole drilled into the upper arm support and then securing this shaft to the forearm support. In this way the forearm support can rotate freely while attached securely to the upper arm support.  Finally the exoskeleton is strapped to the left arm by means of one strap which is attached to the top of the exoskeleton and passed over the shoulders and secured to a belt loop and three straps which secure the exoskeleton directly to the left arm.

## Conclusion

The left arm exoskeleton controlled by the EMG signal from the biceps successfully amplifies the power exerted by the bicep and can be used to assist in bearing a load in the hand or merely helping the forearm in its natural movement. The exact value of exoskeleton's output torque from the measured RMS value is not yet completely determined, yet this translation from inputted EMG signal, to RMS value, to outputted duty cycle, to motor torque can be determined with further experimentation. This exoskeleton design and control system can be improved and added to in order to design an exoskeleton of the arm with more degrees of freedom including wrist and shoulder movements.



Figure 11. Final design modeled on the left arm.

# References

Scott, Day Dr. "Important Factors in Surface EMG Measurement." *Bortec Biomedical.* PDF    file.

Sellers, Bill. "Introduction to EMG." PDF file. http://mac-huwis.lut.ac.uk/~wis/lectures/

University of Utah. "Electromyogram (EMG) Detector with Audiovisual Output." PDF file.

Konrad, Peter. "The ABC of EMG." April 2005. PDF file

Hidalgo, M., Sanchez A., Tene G., "Fuzzy Control of a Robotic Arm Using EMG Signals". Department of Automatization and Industrial Control. 2005. PDF file.

De Luca, Carlo J., "A Practicum on the Use of Surface EMG Signals in Movement Science". DELSYS. May, 2008. PDF file.

"The EMG Signal." PDF file.

"Apparatus For EMG Measurement". PDF file.