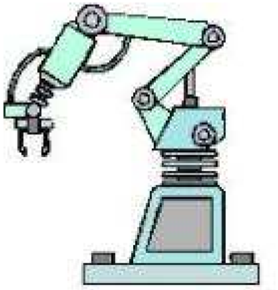
# Motor Control Laboratory

(Electromyography Application)



**CleveLabs Laboratory Course System Version 6.0**

## Introduction

As you previously learned in the Electromyography I laboratory session, electromyography (EMG) is a summation of all action potentials occurring in a muscle at a single time. The EMG signal occurs as a potential that can be recorded on the surface of the skin with standard snap electrodes. The electrical signal is on the order of millivolts and the amplitude typically increases with increased amounts of muscle force. As the muscle force increases, more and more muscle fibers are recruited by the nervous system which increases the amplitude of the summation of the electrical potentials that are generated.

EMG has many practical clinical applications including biofeedback, biomechanics research, and use as a control source for rehabilitative devices such as functional electrical stimulation to paralyzed muscles and myoelectric prosthetics. Additionally, monitoring EMG has lead to a greater understanding of muscle properties, given insight into how muscles work together to coordinate tasks, and yielded information about neuromuscular disorders. For example, a person may have been involved in an accident that caused them to lose one of their arms from the elbow down. Therefore, a prosthetic arm may be attached to the person's residual limb to improve function. The prosthetic arm may have a few to several degrees of freedom available including elbow angle and hand opening/closing. Therefore, a control source must be established to modulate the degrees of freedom of the prosthetic limb. One option is to use remaining voluntary EMG of the arm to control the prosthetic limb. The EMG can be processed and used as an input to control the degrees of freedom. This is referred to as a myoelectric prosthetic device.

In this laboratory session, students will use real-time EMG recordings from muscles of the arm to control a virtual robotic arm. Different types of signal processing techniques will be applied to examine the effects on control.

**Equipment required:**

- CleveLabs Kit
- CleveLabs Course Software
- Five (5) Contour Snap Electrodes
- Five (5) Snap Leads
- Microsoft® Excel, MATLAB®, or LabVIEW™

# Background

## EMG Signal Processing

There are several methods that can used to process the EMG signal. As you learned in previous laboratory sessions, filtering can be useful to eliminate unwanted noise from biopotentials. High and low pass filtering are commonly used to process EMG for use as a control signal. In order to remove high frequency noise, a low-pass filter can be applied to the EMG data. This will effectively smooth the EMG signal. When used as a control signal, low pass filtering can provide smooth control and remove noise and jitter. On the other hand, a high-pass filter can be applied to remove low frequency noise such as motion artifact. A high pass filter will not provide smooth control, but will increase the response time of the system to allow for quick transitions. There are many tradeoffs between using a high pass and low pass filters in signal processing. The example below (Fig 1) shows a raw EMG signal and then the same signal low pass filtered at 25 Hz and high pass filtered at 25 Hz. Notice how low pass filtering the EMG signal removes much of the information content of the signal. Notice how the high pass filter removes the low frequency noise from the signal.

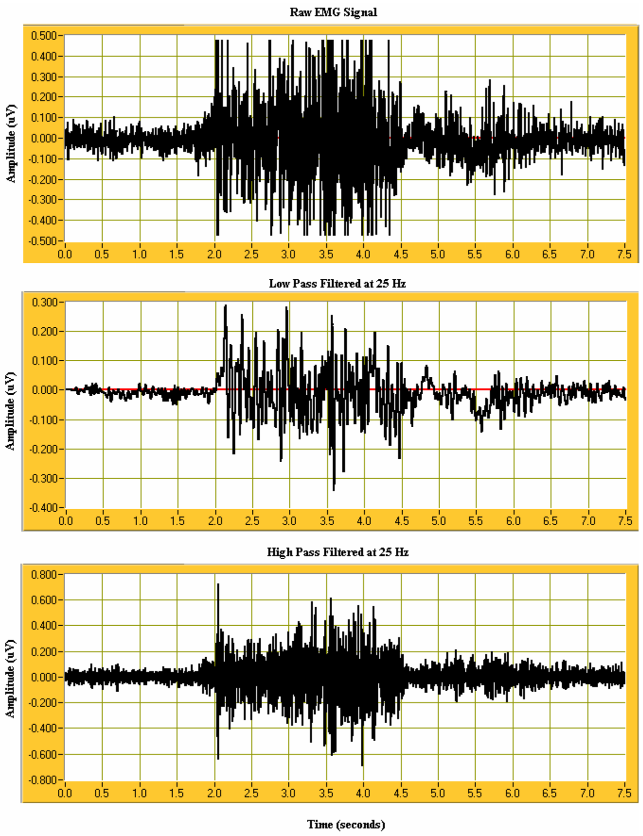


**Figure 1:** Low and high pass filtering of the EMG signal. Note the different Y –axis values.

In addition to filtering, there are other digital signal processing techniques that can be applied to EMG signals. For example, the EMG signal is often rectified since both a high negative or high positive value refers to an increase in muscle activity. Often times a root mean square (RMS) value or integral of the EMG signal over discrete intervals of time are used as a processing technique. This may be a sliding window interval or discrete blocks of time. Completing a bin integral or bin RMS value of the EMG signal acts as a low pass filter and can help to smooth the EMG data. For the laboratory experiments that you will complete below, a sliding RMS window is used to control the virtual robotic arm.

There can be several problems with using the EMG signal as a control source. First, normalization can be an issue. Normalization refers to finding a maximum and minimum value for the EMG signal and then normalizing all values to those levels so that your control source varies between 0 and 1. If the subject is not completely relaxed during the initial calibration or they did not generate a maximum force, the normalization during the control will be affected. Additionally, muscles fatigue over time. Muscle fatigue causes the frequency of the EMG signal to decrease, but the amplitude of the EMG signal to increase. Therefore, the original calibration may not be valid if the subject is using the system for a long time and fatigue occurs.

## Tenodesis Grasp

Tenodesis grasp is a passive property of the hand that occurs when you extend your wrist with your palm facing down and relax the muscles in your hand. When the wrist is extended, the fingers are passively flexed. If an object were between the fingers and the palm, this would cause a grasp on the object. Obviously, this is a weak grasp, but consider the case of a spinal cord injury at the C7 level. An injury at this level leaves a subject with wrist extension, but no voluntary control over finger flexion or extension. The subjects can use the tenodesis grasp to passively flex the fingers and hold on to light objects for manipulation.

## Myoelectric Prosthetic Control

The amputee population often utilizes prosthetic devices to restore function after the injury. For example, someone who has lost their arm above the elbow in a car accident may use a prosthetic limb that consists of a hand and an elbow joint. A method for controlling the opening and closing of the hand and the elbow angle must be developed. One control input to use is EMG from their remaining voluntary muscles. Prosthetics that utilize EMG control are referred to as myoelectric prosthetics.

During this laboratory, you will use the EMG from your arm to control two degrees of freedom of a virtual robot arm on the screen. EMG from your biceps will be used to control the elbow angle, while EMG from your wrist extensors will be used to control the grasp of the claw (i.e. a tenodesis grasp).

## Experimental Methods

*Experimental Setup*

This laboratory will record EMG in the subject's biceps and wrist extensor muscles. You should watch the setup movie included with the software prior to beginning the experimental setup.

1. Your BioRadio should be programmed to the "LabMotorControl" configuration.

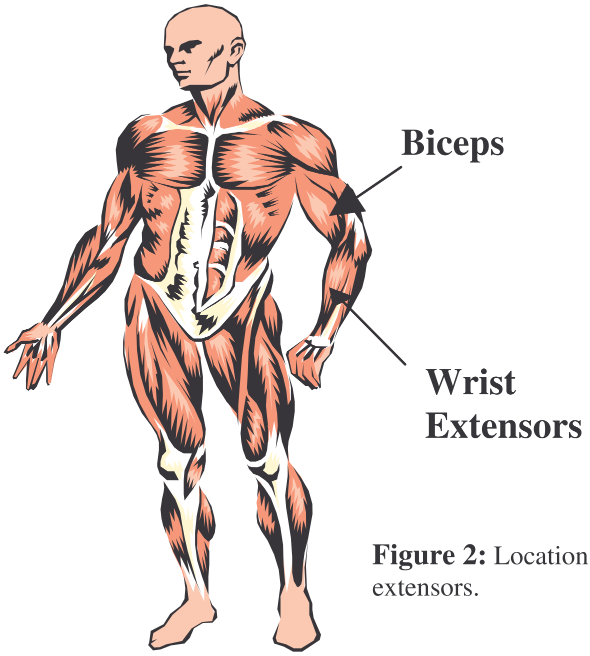


**Figure 2:** Locations of the biceps and wrist extensors.

2. For this laboratory you will need to use five snap electrodes from the BioRadio Lab Kit. Remember that the electrode needs to have good contact with the skin in order to get a high quality recording. The surface of the skin should be cleaned with alcohol prior to electrode attachment. For the best recordings, it is best to mildly abrade the surface with pumice or equivalent to minimize contact resistance by removing the outer dry skin layer. Attach two electrodes about one inch apart above the biceps, attach two electrodes about one inch apart on the wrist extensors (these muscles are located on the dorsal side of the forearm about half way between the wrist and elbow), and attach one electrode to the bony part of the elbow to use as the reference and ground electrode.

3. After the electrodes have been placed on the subject, connect one snap lead to each electrode. Then, connect those snap leads to the harness inputs channels 1, 2, and the ground using the picture below as a reference (Fig 3). The leads on the harness are stackable allowing one snap lead to be plugged into more than one connector lead.

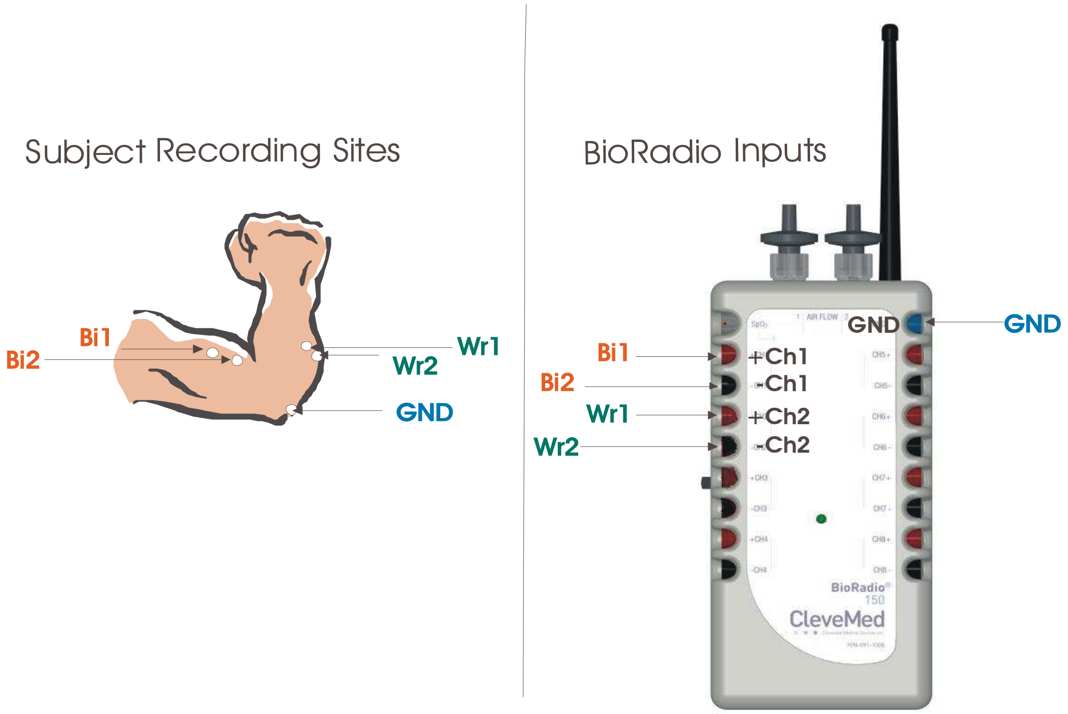


**Figure 3:** EMG Setup

*Procedure and Data Collection*

1. Run the CleveLabs Course software. Select the "Motor Control" laboratory and click on the "Begin Lab" button.

2. Turn the BioRadio ON.

3. Set the data collection interval to be 100ms, then click on the green "Start" button.

4. Click on the EMG data tab to start the EMG data scrolling on the screen.

5. Have the subject hold out their arm with the palm facing down. Then have someone else hold their hand on top of the back of the subjects hand to provide resistance for an isometric contraction. Then instruct the subject to try and extend their wrist against this resistance. You should see the wrist extensor EMG increase. Report a screen shot of this.

6. Next, have the subject turn their hand over so that the palm faces up. Another person should hold their hand on the subjects palm to provide resistance. Now instruct the subject to try and flex their elbow against the resistance. You should see the biceps EMG increase. Report a screen shot of this.

7. Click on the spectral analysis tab.

8. Click on the time domain tab. Select the channel to process to be channel 1 (biceps). Then instruct the subject to make quick elbow flexion and extension movements. Notice what happens to the raw EMG signal during the motion as a result of motion artifact. Report a screen shot of this.

9. Now turn on the high pass filter and set the high pass cutoff to be 20 Hz. Set the switch to filtered data. Now repeat the motion above and note what happens to the motion artifact. Report a screen shot of this.

10. Turn off the time plot and click on the processing and application tab. In this application you are going to use the EMG from the subject's arm to control a virtual robot arm on the screen. The EMG from the subject's biceps will be used to control the elbow joint of the robot arm. The EMG from the subject's wrist extensor muscles will be used to control the claw of the subject. As EMG from the biceps increases, the elbow angle will close proportionally. Similarly, when the EMG from the wrist extensors increases, the claw grasp will close proportionally.

11. The signal used to control the robot arm is processed in the software. Your data collection interval should currently be set to 100ms. Every data collection interval the raw EMG data points are added together for a signal channel. This value is then used as the control signal to the robot arm. The position of the robot arm is updated each data collection interval. Essentially, during every data collection interval, the EMG data is stored in bins and then every point in the bin is added together to create a single number that will be used to control the robot arm position during the next data collection interval.

12. First set the filter characteristics for each signal. Set the filter type to highpass for each signal, the highpass cutoffs to 20Hz, and set the filter orders to 4. (Later you will adjust these values to see the effect on control, but for now they should be set to these values).

13. You will need to normalize the EMG values during this application. A normalization routine has already been written for you. We will normalize the EMG values to the range 0-1. You may remember we looked at normalization in the digital signal processing laboratory session. Instruct the subject to relax all the muscles in their arm. Then turn on the normalize wrist switch and click on the reset normalization button. This will reset the maximum and minimum EMG values for the wrist extensors. Then instruct the subject to normally extend their wrist. This should cause the maximum value to increase. After they extend their wrist, you should immediately turn off the normalize wrist switch to

stop the normalization procedure. The values under max and min for the wrist will now be used to normalize the wrist extensor EMG to the 0-1 level.

14. Repeat the normalization procedure for the biceps.

15. You are almost ready to control the robot arm. You can control both the elbow angle and the claw or choose only one to control at a time using the control options drop down menu. Right now select “Elbow and Claw”, however, later you may look at only one.

16. The current control value box has four parameters.

    a. Wrist Ext Normalized is the normalized (0-1) value of your wrist extensor EMG. When this value is 0, the wrist extensors are at a maximum and the claw should be closed. When this value is 1, the wrist extensors are at a minimum and the claw should be open.
    b. Biceps Normalized is the normalized (0-1) value of the biceps EMG. When this value is 0, the biceps should be at a minimum and the robot elbow should be extended. When this value is 1, the biceps should be at a maximum and the robot elbow should be completely flexed.
    c. The Wrist Ext Actual shows the actual value of the wrist extensor EMG.
    d. The Biceps Actual shows the actual value of the biceps EMG.

17. Turn on the Robot Arm Control Switch. Instruct the subject to completely relax their arm. The robot arm should be extended with the claw open. Report a screen shot of this.

18. Now have the subject maximally contract both their biceps and their wrist extensors. The robot arm should now be flexed with the claw closed. Report a screen shot of this.

19. Turn on the target switch and have the subject try to control intermediate levels of the elbow angle and match the target levels.

20. Finally, adjust the filtering parameters and see how it affects control of the robot arm. Try both low and high pass filtering with different cutoffs. You should renormalize the parameters each time that you adjust the filter parameters. Save several data files while you try to control intermediate levels of the elbow angle targets using different filtering parameters.

    For example, start with a low pass filter and set the cutoff to 30 Hz. Next, keep the low pass filter type, but change the cutoff to 100Hz. Notice how the smoothness of control changes as a function of the filter type. Notice how the transition speed of the control changes as a function of filter type.

21. Change the data collection interval and note what effect that has on your ability to control the robot arm.

## Data Analysis

Using the post processing toolbox, MATLAB or LabVIEW, open the saved data files that you collected during the robotic arm control experiments. Calculate such quantitative measures as time to target, undershoot, overshoot, and the RMS error around the target for each control method that you used. The target and your angles will appear in the data files with many 0's interspersed between. This is because the EMG and the arm angles were sampled at different frequencies. You should disregard the 0's in your analysis.

## Discussion Questions

1. Why can't the average or bin integral be performed without first rectifying an EMG waveform?
2. Many special signal-processing techniques can be applied to extract or enhance certain properties of the EMG. Explain why one would use the RMS value rather than the average value of an EMG signal, and what signal property it enhances.
3. In terms of control, what are the tradeoffs between high pass and low pass filtering?
4. Why might someone want to high pass filter the EMG data? Think about the frequency range of the EMG signal and sources of artifact in the signal.
5. From the analysis that you have completed on the EMG signals, describe some limiting factors on the number of discrete EMG levels that could be used as a control source.
6. Spinal cord injury subjects at the C5/6 level lose the ability to open and close their hand. By electrically stimulating muscles in a coordinated fashion, hand grasp could be restored. One control source for this system may be to use the EMG from a voluntary muscle to proportionally control the strength of the stimulation. Outline the characteristics of a system that could be used to control this. What tools that we have (or haven't) discussed would you need, and how would they be used?
7. How would muscle fatigue affect the output of the system outlined above? Describe ways to avoid or work around fatigue related output differences.
8. What do the quantitative measures that you calculated during the robotic arm control session tell you about the effects of filtering parameters on the control of a myoelectric prosthetic device?

## References

1. Guyton and Hall. Textbook of Medical Physiology, 9th Edition, Saunders, Philadelphia, 1996.

2. Kandel ER, Schwartz JH, Jessel, TM. Essentials of Neuroscience and Behavior. Appleton and Lange, Norwalk, Connecticut, 1998