INTRODUCTION TO BIORADIO AND SIGNAL PROCESSING

OBJECTIVE:

The purpose of this laboratory is to familiarize you with the BioRadio Software and review some simple signal processing techniques.

- In **Part 1**, you will investigate the effect of noise, how sampling rate affects the reconstruction of data, and quantization problems in digitalization.
- In **Part 2**, you will study how signal processing techniques (such as spectral analysis and filtering) are used to separate physiological data from interference as well as how muscle contraction affects the electromyogram (EMG).

Specific instructions for the lab report are designated with the  symbol.

PART 1: Introduction to Data Acquisition and the Lab Course Software

INTRODUCTION:

The BioRadio 150 wireless physiological signal monitor consists of a Transmitter, a Receiver Assembly (the receiver, USB cable), and other accessories (Test Pack). The transmitter collects signals from electrodes attached to the subject, performs analog-to-digital conversion (ADC), encoding, and transmitting of all signals. The signals are communicated using radio transmitters with carrier frequencies ranging from 902 – 928 MHz. The receiver assembly collects the data, performs error detection and correction, and then sends the data to the PC where the data can be stored and monitored.

BACKGROUND:

Noise:

As with any electrical measurements, noise is present during the recording of biopotentials. This can be a major problem since its amplitude is often larger than the biopotentials themselves. One of the most common sources of noise is 60 Hz AC power: a subject acts as an antenna that receives this 60 Hz noise through electrical and magnetic field coupling.

Noise rejection circuits such as a differential amplifier can be used to reduce this noise. Biopotential signals can be measured by placing electrodes in two locations. Since 60 Hz noise appears evenly on both locations, subtracting the two channels will effectively cancel out the 60 Hz noise, leaving only the potential difference across the two channels. In order to provide high

input impedance to the circuit, voltage followers can be added to the input sources. The final circuit is a general-purpose instrumentation amplifier (see Figure 1) with gain A_{vd}.

$$A_{vd} = (1 + 2\frac{R_3}{R_G})(\frac{R_2}{R_1})$$

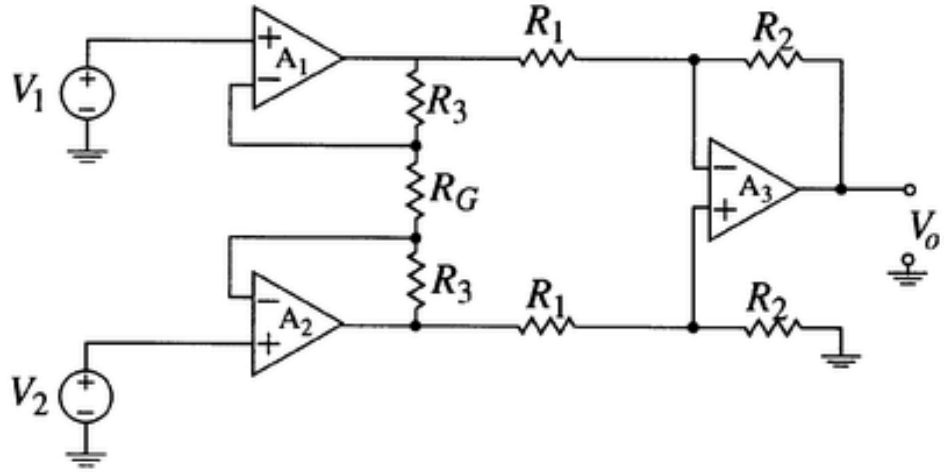

FIGURE 1: General purpose instrumentation amplifier. Note the voltage followers at the two inputs.

The BioRadio already has built-in circuit that removes common mode noise from the recorded data. Some more advanced methods of removing 60 Hz noise include using notch (band-stop) filters and digital filtering.

Noise can also arise from the human body itself. There are many electrical events in the body and it is possible to record an undesired activity along with the desired biopotential.

Sensing, Reference, and Ground Electrodes:

You will notice on the BioRadio harness that there are sixteen sensing inputs (eight channels), two reference inputs, and a ground input. Sensing electrodes are either black (negative) or red (positive) on your universal differential harness. These electrodes work in conjunction with the reference electrodes (REF) and ground (GND) electrodes to define the potential measured by the BioRadio. The universal differential harness allows you to set up each channel as either single ended or differential. For differential channel configurations, attach both the (+) and (–) leads to the area being monitored. For single ended channel configurations attach only the (+) lead to the area being monitored then take the corresponding (–) lead and connect it into the female end of either reference input. Each universal reference connector has both a female and male coupling for you to use. For each channel you configure for single ended use, simply stack the (-) leads of the respective channels one on top of the other. You can have multiple (-) leads stacked to any one reference. The reference inputs are redundant connections tied together internally. A potential must be measured between two electrodes. Therefore, the potentials that you measure with the BioRadio are measured between your sensing electrodes and the reference electrodes. The ground connector on the BioRadio harness defines the zero output voltage. This is useful

when the system that you are measuring does not share the same ground with the rest of the system. In this case, the BioRadio can be thought of as one system where as the system that we are measuring (i.e. biopotentials from the body or external sensors such as airflow cannulas or respiratory effort belts) is separate. The ground electrode allows you to define a specific offset and keeps the "floating" input signal you are measuring between the BioRadio system rails.

Data acquisition:

The BioRadio uses a computer interface to display and record biopotentials. The measurements have a continuous range of voltage varying over time (analog signal). This implies that it has infinite number of possible values. Therefore, a computer samples discrete voltage levels at discrete points in time and then reconstructs the continuous signal from these points using an analog to digital converter (ADC). The first step of ADC is sampling. It works by recording the voltage at a discrete point of time of the original analog signal. Once sampled, this sample is converted into a binary value through the process of quantization. Typical resolutions for data acquisition are 8, 12 and 16 bits in the BioRadio. This process is then repeated for the next sample. Other data acquisition issues include aliasing, which according to Nyquist theory, requires the sampling rate to be at least twice of the highest frequency component of the signal. As illustrated in Figure 2, it is important to sample at a frequency that is greater than twice the highest frequency of the signal.

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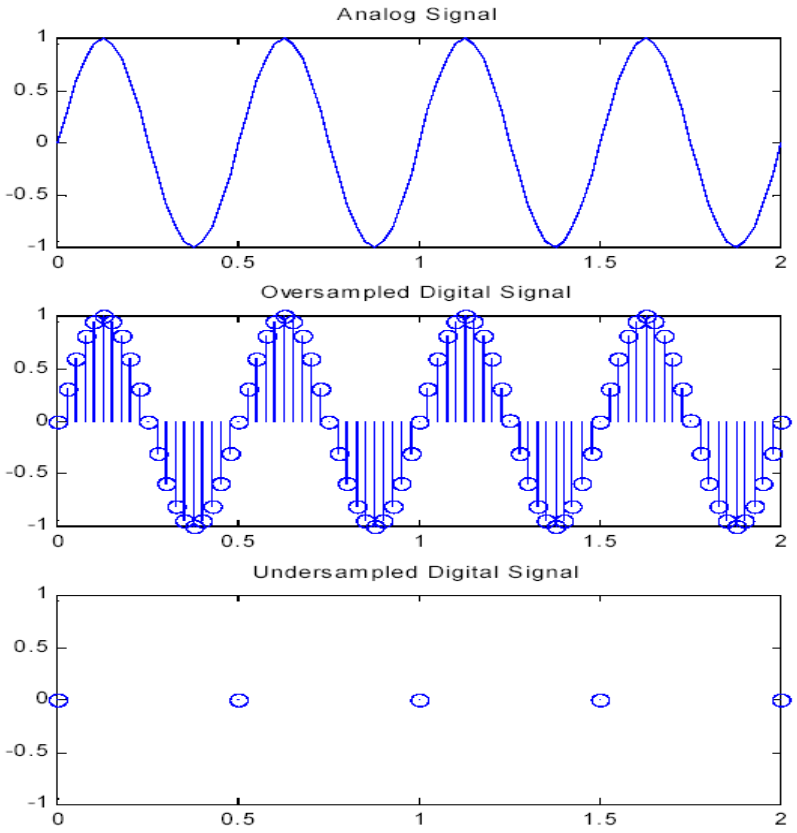


FIGURE 2: When a signal is sampled at a frequency greater than 2 times the highest frequency, it can be accurately reconstructed. If sampling is slower, it will lead to aliasing.

Another aspect of ADC is the quantization error problem. Quantization error can be thought of as not having sufficient levels to represent the data accurately. For example, a 2-bit system can only represent 2^2 or 4 discrete values, whereas an 8-bit system can represent 2^8 or 256 discrete values. Anything measurements between these levels would be rounded off to one of the discrete levels. Truncation is responsible for quantization noise. The more bits you have, the greater the resolution of your measuring system. Lastly, data acquisition can generate very large files very rapidly. For example, a 10-minute 16 channel EEG recording with sampling frequency of 200Hz and 16 bits per channel will generate a file that is

*16 bits/channel * 200 samples/second * 600 seconds * 16 channels = 30720000 bits or 3.84 Megabytes.*

Experimental Methods

Each laboratory in this course uses a very similar software interface. This laboratory will explain in great detail how to use the Laboratory Course software. Later laboratories will build upon this laboratory and will not explain all of the software features in as great detail. This laboratory is meant to be an introduction to the Lab Course software as well as an introduction to Data Acquisition. When you first run the CleveLabs software, the main menu will appear as shown below:

The first thing that you need to do is enter your student or group name in the top right corner and click on Log In. **You need to log in so that all of your saved data and reports are sent to the appropriate user folder.** You will not be able to enter any laboratory sessions until you are logged in.

Where are Data and Reports Stored?
Whenever you save data files in a laboratory session, the saved data will be stored in the

following location: C:\Users\Student\Documents\CleveLabs\data\"Login Name". "Login Name" refers to the user name you entered on the front panel of the CleveLabs software interface.

You can later access the saved file by right clicking on the Start button of the Window and clicking on explore.

Experimental Setup:

1. Connect the Test Pack to the transmitter. If you are using a BioRadio 150, you should connect the testpack outputs to channels 1 and 2 on the unit. The blue test pack lead should be connected to ground input on the BioRadio. The metal limo connector should be connected to the pulse ox input. A red lead should be connected to a positive input of channel 1 and 2. A grey lead should get connected to a negative input of channel 1 and 2.
2. From either the "All Laboratories" or the "Engineering Basics" laboratory sets, select the Data Acquisition Basics" laboratory. Then click on "Begin Lab" in the bottom right hand corner.

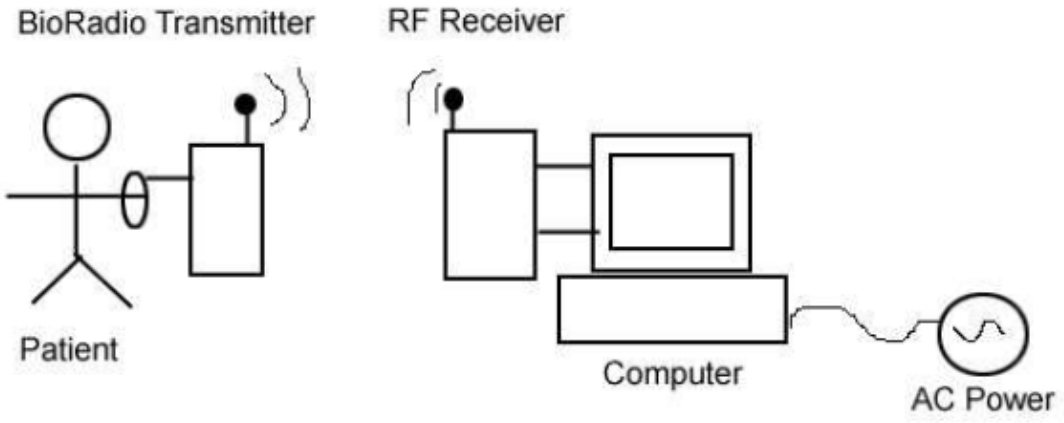


FIGURE 3: Schematic representation on the connection of the transmitter and receiver

Each module has the same "Main Controls". Clicking on "Start" will activate the software. Clicking on "Stop" will stop the software from running. Clicking on Main Menu will cause the software to exit the individual lab and return to the main menu lab selector. The main control buttons also include "Save Data" and "Screen Capture". For each laboratory session, you can save real-time raw and processed data to a file by clicking on the "Save Data" button. When you click the "Save Data" button, you will be prompted for a file name. Data will be saved to the file folder location described above.

The software interface for each lab also has several "Tabs" ("Test Pack Data", "Signal Noise", "Sampling Rate", and "Resolution") that you may select according to the various sections in the experiment.

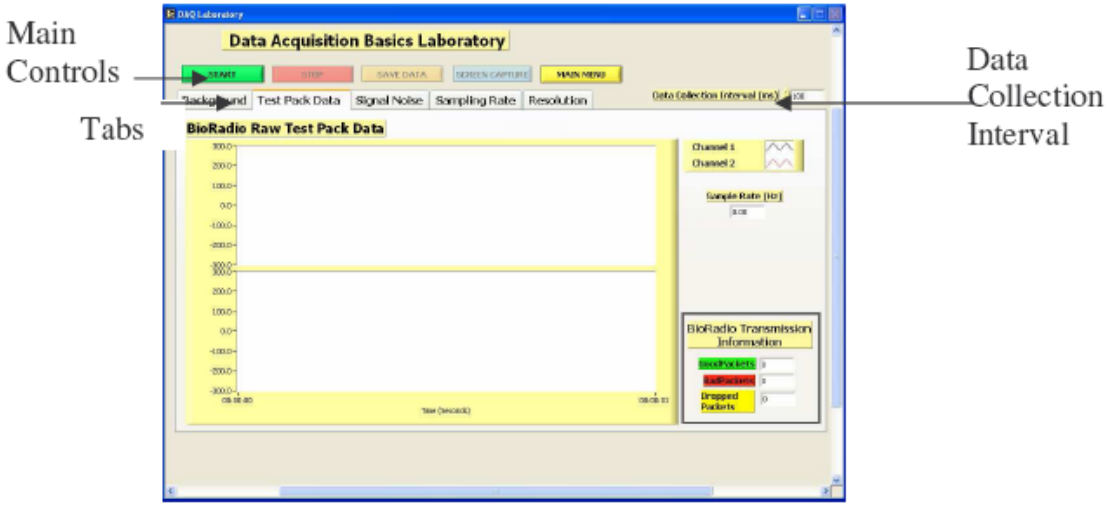


FIGURE 4: Main control window

Transmission Information:

The number of "Good Packets" indicates the amount of readable data that is received from the transmitter for each run. Typically, this number should be increasing when the transmitter is turned on. The number of "Bad Packets" indicates the amount of corrupted or unreadable data for each run. Typically, this number should remain close to zero and should not increase by a great deal during the lab. Finally, the number of "Dropped Packets" indicates the number of packets that were sent by the transmitter, but missed by the software. Dropped data packets can occur for several reasons. First, the transmitter may be located too far from the receiver and is out of transmission range. Secondly, another device may be causing interference in the transmitted signal. In general, the number of dropped packets should remain close to zero.

Data Collection Interval:

"Data Collection Interval" specifies how often the software retrieves data from the receiver. The serial port has a finite buffer. Therefore, only a limited amount of data can be stored before it starts to overfill. Therefore, if you set the data collection interval to be too high, the buffer will overfill and you will begin to see the "Dropped Packets" indicator begin to rise.

Auto Scaling Plots:
Plots in the lab course software have an auto scale feature. This can be useful, however in some instances you may wish to turn it off. Right clicking on the axis and then selecting or turning off the auto scale feature allows you to manually adjust the axis scale. To manually adjust the scale, simply double click on the scale numbers and type in your new range.

EXPERIMENT:

- Make sure the receiver is properly connected to the serial port on the computer and is powered on. Make sure your transmitter is still connected to the test pack. Turn the transmitter ON.
- Click on the green "Start" button.
- Click on the "Test Pack Data" tab. You should see the BioRadio Raw Test Pack Data plot. Make sure that the time scale is set to 1 second.

1. *What is the signal generated from the Test Pack? Describe it in terms of its wave-shape, frequency and amplitude.*

- Save a screenshot of the signal from the Test Pack. Click Save Capture and type in the filename *"lab1raw"*. Check afterwards that the screenshot saved successfully.
- Examine the BioRadio Transmission Information box at the bottom right hand of the screen. A common cause for a dropped packet is when the transmitter is out of range from the receiver. Keep moving the BioRadio transmitter further and further from the receiver and have someone else watch the transmission information. You can test the range of your BioRadio transmitter and receiver this way. Note the range of your BioRadio.

2. *What is the largest physical distance the transmitter/receiver pair can tolerate before performance is affected?*

- Bring the BioRadio transmitter back into an appropriate range so that it is no longer dropping packets.
- Now begin increasing the data collection interval. Note the largest data collection interval you can use before the buffer overflows and you begin to drop data packets. Do not set the data collection interval any higher than this for any of the laboratories.

3. *Investigate large and small data collection intervals. List the Pros and Cons for using a large data collection interval (before buffer overflows).*
4. *Why should each transmitter/receiver pair use a unique carrier frequency?*
5. *For input ranging from ±61mV using 16 bits per sample, what is the range of values represented by each bit?*
6. *Assume you are going to use the BioRadio to record two channels for 30-minutes with the BioRadio configuration given in the lab procedure. How many bytes would you expect that file to be if there are 12 bits/sample?*

Signal Noise:

- Click on the tab labeled **"Signal Noise".** We shall artificially superimpose some noise signal onto the test pack data.
- Set the time scale to be 0.5 seconds and then turn on the **"Noise Plot".**
- Set the noise type to be **"None".** You should see the BioRadio Data and the Noise data plotted on top of each other.

- Now set the type of noise to **"Uniform White"** and the amplitude to 25uV. You should now see the noise in the Noise plot.

7. What is the characteristic of a uniform white noise?

- Now continue increasing the white noise amplitude until you can no longer tell that a square wave exists.
- Now set the type of noise to **"Sine".** This simulates what 60Hz noise could look like on top of the square wave.
- Examine the other types of noise and their effect on the signal.

8. What sources of noise would you expect when recording EMG, EEG, and EOG signals <u>besides</u> 60 Hz from power sources?

<u>Sampling Rate:</u>

- Click on the tab labeled **"Sampling Rate".** You will explore how sampling rate affects the reconstruction of signal.
- Set the resample rate to be 960 Hz. Set the time scale to be 1 second then turn on the Sampling Rate Plots.
- If the time scale shifts from 1 second when you start to run, just switch off the plot, reset the time scale, and switch the plot on again.
- Turn off the sampling rate plot. Right click on each plot and select **"Clear Chart".** Reset the sampling rate to 96Hz and turn the sampling rate plots back on.
- Repeat the last two steps for each sampling rate.

9. Examine the data with 24Hz sampling and with 12Hz sampling. What happens when you drop below a 20Hz resample rate?

- Turn off the sampling rate plots.

PART 2: Robot Arm Control using Electromyogram (EMG)

INTRODUCTION:

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, you 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.

BACKGROUND:

EMG Signal Processing

There are several methods that can used to process the EMG signal. As you learned in previous laboratory section, 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 any tradeoffs between using a high pass and low pass filters in signal processing. The example below (Fig 6) 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.

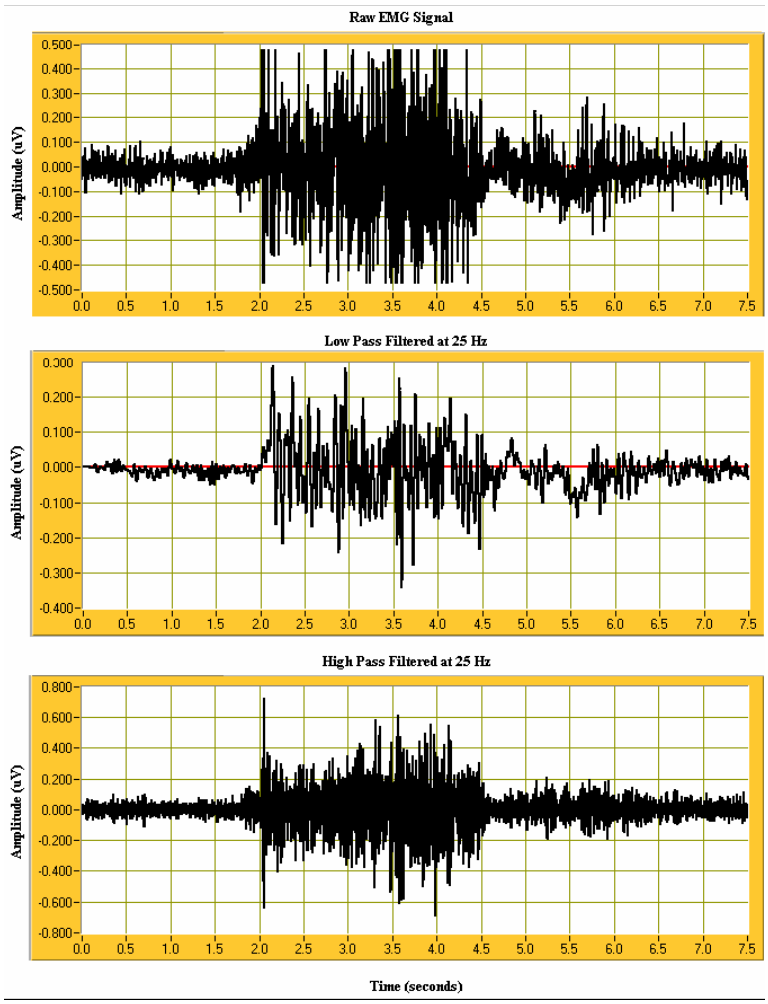


Figure 6: Low and high pass filtering of the EMG signal. Note the different Y –axis values.

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

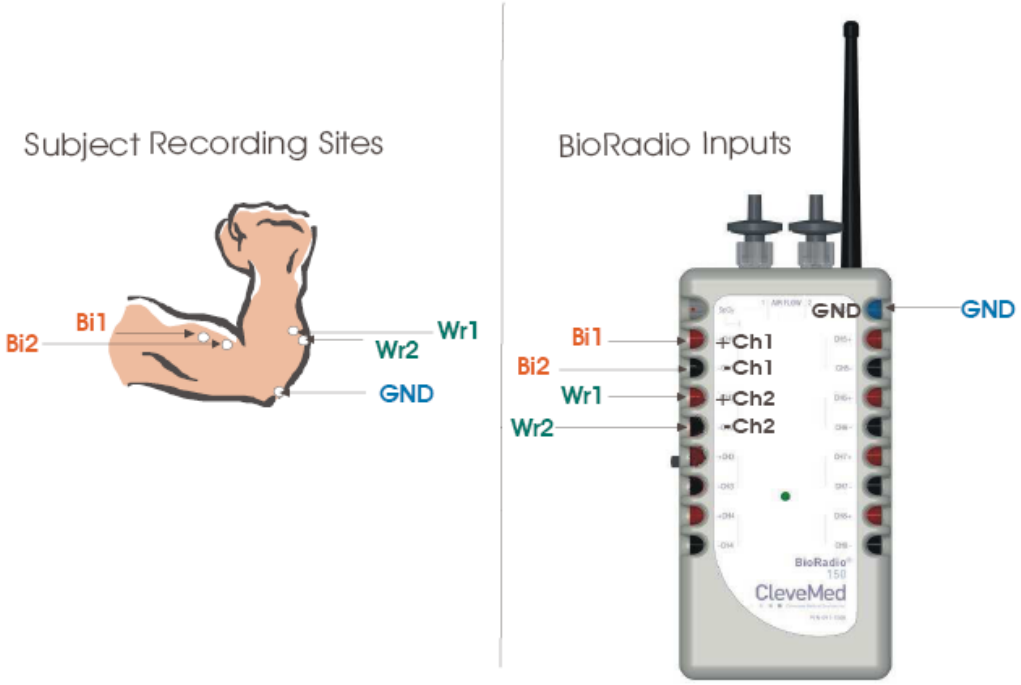
The amputee population often utilizes prosthetic devices to restore function after the injury. For example, someone who has lost their arm above the elbow in a car accident may use a prosthetic limb that consists of a hand and an elbow joint. A method for controlling the opening and closing of the hand 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).

EXPERIMENT:

During this laboratory session you will record two channels of EMG from your upper extremity. You will record one channel from your biceps muscle and another from your wrist extensor muscles.

- Your BioRadio should be programmed to the "LabMotorControl" configuration.
- Switch off the transmitter and disconnect the testpack. 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 abrade the surface mildly 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.
- After the electrodes have been placed on the subject, connect one snap lead to each of the four electrodes. Then, connect those snap leads to the harness inputs channels 1, 2, references, and the ground using the picture below as a reference. The leads on the harness are stackable allowing one snap lead to be plugged into more than one connector lead.



- Connect the universal harness to the BioRadio transmitter and turn the transmitter on. Run the CleveLabs Course software. Log in and select the "Motor Control" laboratory session under the Clinical Applications subheading and click on the "Begin Lab" button.
- Turn the BioRadio ON. Set the data collection interval to be 100ms then click on the green "Start" button.
- Click on the EMG data tab to start the EMG data scrolling on the screen.
- 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.

10. Describe the changes in the wrist extensor EMG when you extend your wrist against the resistance with the palm facing down. Provide a screen shot of this.

- 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.

11. Describe the changes in the bicep EMG when you flex your elbow against the resistance with the palm facing up. Provide a screen shot of this.

- Click on the spectral analysis tab.
- 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.

12. What happens to the raw EMG signal because of motion artifact due to quick elbow flexion and extension movements? Provide a screen shot of this.

- 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.

13. With the high pass filter enabled, what happens to the raw EMG signal because of motion artifact due to quick elbow flexion and extension movements? Provide a screen shot of this.

14. In terms of control, what are the tradeoffs between high pass and low pass filtering? 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.

- 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.

- 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.

- 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).

- 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. 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.

- Repeat the normalization procedure for the biceps.

- 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.

- The current control value box has four parameters.
  I. Wrist Ext Normalized is the normalized (0-1) value of your wrist extensor EMG. When this value is 1, the wrist extensors are at a maximum and the claw should be closed. When this value is 0, the wrist extensors are at a minimum and the claw should be open.
  II. 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.
  III. The Wrist Ext Actual shows the actual value of the wrist extensor EMG.
  IV. The Biceps Actual shows the actual value of the biceps EMG.

- 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.

15. What are the normalized wrist extensor and bicep control values for achieving complete relaxation? Is the robot arm extended with claw open? Provide a screen shot of this, showing both the arm and the control values.

- Now have the subject maximally contract both their biceps and their wrist extensors. The robot arm should now be flexed with the claw closed.

16. What are the normalized wrist extensor and bicep control values for achieving maximum contraction? Is the arm flexed with the claw closed? Provide a screen shot of this, showing both the arm and the control values.

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

- 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 or screencaps while you try to control intermediate levels of the elbow angle targets using different filtering parameters as given in the table below. Notice how a) the smoothness and b) the transition speed of the control changes as a function of the filter type.

Filter Type	**Cutoff**
Low pass filter	**30 Hz**
Low pass filter	**100 Hz**
Low pass filter	**10 Hz**
High pass filter	**30 Hz**
High pass filter	**10 Hz**
High pass filter	**60 Hz**

17. Describe how changing the filtering parameters affect control of the robot arm. (I.e. how the smoothness of control changes as a function of the filter type and cutoffs or how the transition speed of the control changes as a function of filter type and cutoffs.)

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

18. Describe the effect of increasing and decreasing the data collection interval on your ability to control the robot arm.

19. Often times in biomechanics, transducers are used to record the angle of a joint during motion. Explain why even a small amount of noise in the signal may prohibit someone from calculating the angular velocity and acceleration of the joint using the angle data from the transducer.

Lab Write-up Format

title/date	Laboratory title and date the experiment was performed
name	Names of **everyone** in the laboratory group [one **(1)** lab report is to be submitted by each lab group]. Include full names and all student numbers.
purpose	One or two sentences identifying the objective or purpose of the investigation
results/discussion	All questions from the lab investigation and write-up section should be answered here. Any additional observations, analysis performed during the laboratory may be included. In addition, a simple one paragraph explanation of what you did and what you found out should be included at the end of the observations/discussion section. Write this paragraph as if you were explaining your results to someone who is not familiar with the laboratory topic (i.e. someone who hasn't taken this course before). **(maximum of 200 words for this paragraph).**
figures	Print out and include all figures and/or screen shots (All figures/screen shots requested in the lab investigation and write-up section must be included, along with any additional figures that may complement your observations/results).