Analog Conditioning for Bioelectric Signals

By Monique Dubois, ECE '21

Introduction

The human body runs on electricity. Our heart is run by electrical impulses, our brain sends electrical signals through nerves, and our muscles contract when stimulated by electricity. There are many medical devices that measure these electrical signals to ensure that the body is properly communicating. Most commonly used are electrocardiograms(ECG) and electromyograms(EMG). Electromyograms can be broken down into subcutaneous and surface EMG. In subcutaneous EMG, the electrode is placed directly on the nerve, which requires surgical intervention. For surface EMG, or sEMG, the electrode is placed directly on the skin. In ECG, the electrodes are patterned in a specific way to collect the heartbeat, while the EMG collects the electrical data from nerves to measure muscle stimulation. All signals in the body are classified as analog signals. Analog signals are defined as a continuous signal that can take on any value. This is contrasted with digital signals, which can only inhabit discrete values (so that a digital signal could not inhabit 1.5 for example), which are most commonly used in computation. Before the signals from the body can be converted to a digital signal for computational analysis, the signal must be properly filtered and conditioned.

Goals for filtering

When looking at raw data from sEMG and ECG, there is significant noise. Noise in signals is not audible noise, and it means that the signal that is desired is obscured. Similar to how in a loud room, you may not hear what the person next to you is saying, noise in a signal obscures the desired message.

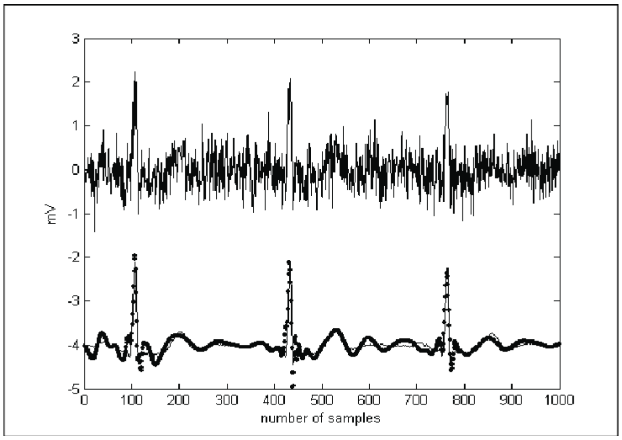


Figure 1: A noisy ECG (top), and a denoised ECG (bottom) [1]

There are several sources of noise in a circuit. In this application, one main source of noise is the skin. For surface EMG and ECG, the skin is a barrier between the signal in the nerves and the electrodes, the measuring device. Since skin is conductive, meaning that electricity can go through it, the signal can be gathered without distortion, but noise is added. This noise is due to dead skin cells obscuring the signal and motion artifacts. The signal is also reduced due to the barrier between the signal and the electrode.

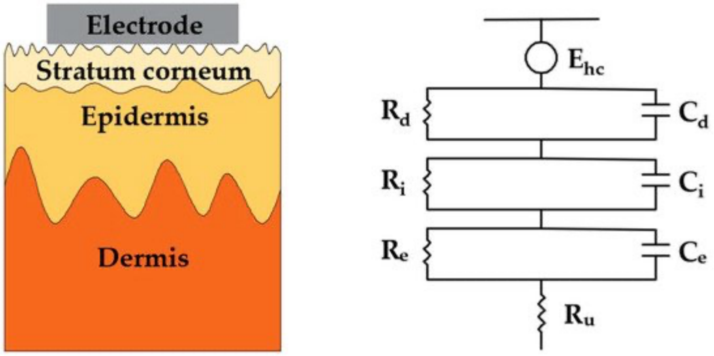


Figure 2: The Schematic and electrical model of the electrode-skin interface for dry electrodes [8]

Motion artifacts occur due to movement of the electrodes and movement of the patient. When measuring a specific signal in the body, there will be interference from other signals in the body that also contribute to noise. This will be increased if the electrodes are farther away from the nerve that should be measured. Preferably, the electrodes should be placed directly above the nerves that are being measured, but there will always be a small percentage of error, which will increase interference. Other sources of noise include electromagnetic radiation and powerline interference. This noise comes from our electronic devices around us and the interference between the devices and our tools to find

Filtering Techniques

Filtering can be used to get rid of some of this noise. For an ECG, the range of expected frequencies is between .05 and 100Hz, while for EMG, they typically lie between 15 and 500 Hz. Thus one should implement a high pass filter and low pass filter to allow only those frequencies through. A high pass filter limits lower frequencies, while a low pass filter cuts off higher frequencies.

Image 2: Frequency response of a low pass filter

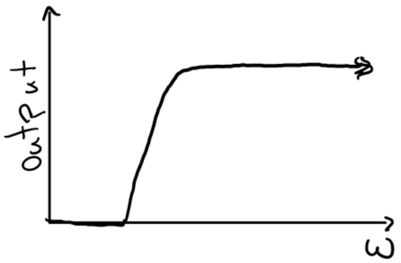
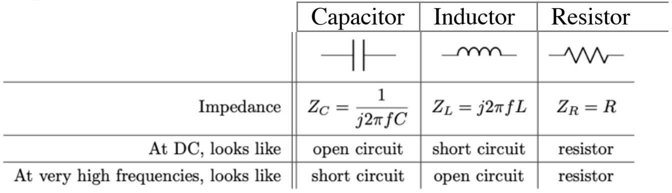


Image 3: Frequency response of a high pass filter

Active versus Passive Filtering

There are two common types of filters, active and passive. A passive filter uses only passive components, or components that do not require outside power, such as resistors, capacitors and inductors. An active filter does need outside power, and typically uses an operational amplifier or a transistor. The idea behind passive filters is that they use the way capacitors and inductors react to different frequencies. Each component has an impedance that describes its relationship to the voltage. This can be used in Ohm's law, Voltage= Current*Resistance as a replacement for resistance.



	Capacitor	Inductor	Resistor
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Impedance	$Z_C = \frac{1}{j2\pi fC}$	$Z_L = j2\pi fL$	$Z_R = R$
At DC, looks like	open circuit	short circuit	resistor
At very high frequencies, looks like	short circuit	open circuit	resistor

Figure 4: Passive component Impedances [2]

Figure 4 shows that for a capacitor, at low frequencies, the circuit is open, or broken, meaning that no voltage is going through, and that at high frequencies, it is short circuited, or behaves as a plain wire, indicating that it lets high frequencies pass. This is the opposite for inductors. Based on that idea, one can design a low or high pass filter with just capacitors, inductors and resistors.

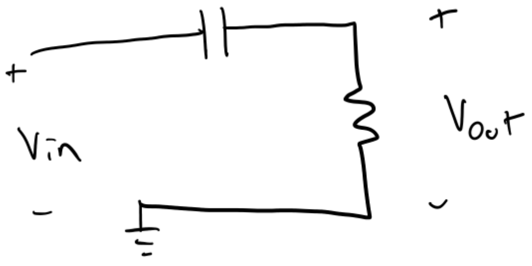

Image 5: a passive high pass filter

It is also common to use operational amplifiers in filtering circuits. An operational amplifier is a chip that requires power, has infinite input impedance and zero output impedance, meaning that it does not act as a load. This is beneficial because it means that the characteristics are independent of the source impedance. Using an active filter allows you to have more control over the filter response, or how fast it changes from the highest voltage to the stop band.

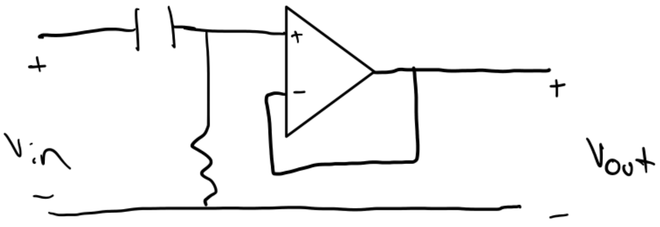

Image 6: An active high pass filter

Order of filters

The most basic filter is considered first order, and only has one order of magnitude in the transfer function. Image 5 and 6 both show a first order high pass filter. It is recommended to use at least a second order filter in filtering bioelectric signals in order to have more control over the cut off points. The higher the order of this filter, the more control one will have over the filtering, however, it will also become increasingly complex.

The transfer function of a circuit compares the input signal to the output signal. For filters, this can tell one what the frequencies are allowed to pass, and what frequencies are cut off.

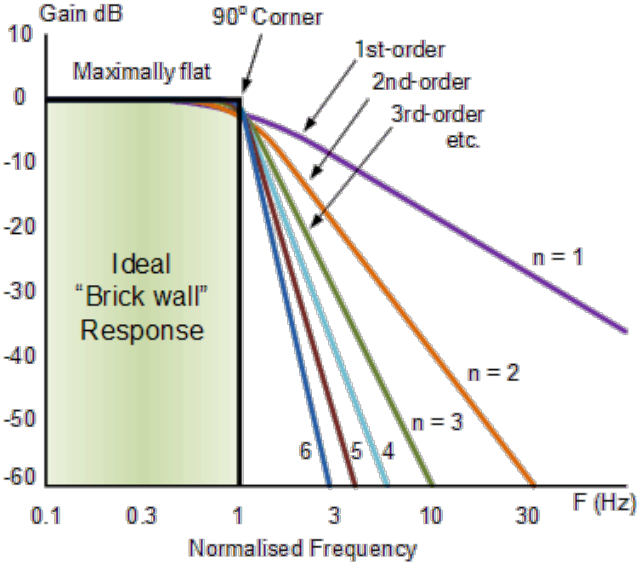

Image 7: How order effects rolloff for the butterworth filter [9]

Filtering schemes

There are different commonly known filtering schemes that implement high and low pass filters that are recommended for this, such as Butterworth, Bessel and Chebyshev. There are tradeoffs to each filtering scheme. In any filter, it does not immediately go from allowing the signal to pass to zero. This is called the cut off. The Butterworth filter has a sharp cutoff, meaning that the signal goes quickly to zero when the pass frequencies have been exceeded. The Butterworth filter also does not allow any peaking. Peaking is a tradeoff, as it is undesired, but can help to prevent phase lagging. In the Butterworth filter, since there is no peaking, there may be increased phase lagging. The Chebyshev filter is an adaptation of the Butterworth that allows the separation of frequencies, which would allow the ability to amplify some frequencies over others. It allows ripples in the pass band, which gives a faster rolloff, however, too many ripples are undesirable, so there is a tradeoff between those factors. The Bessel filter can also be used. This has minimal overshoot, but it has a slow cut off factor. The filtering scheme used will largely depend on the desired response and the method of analysis.

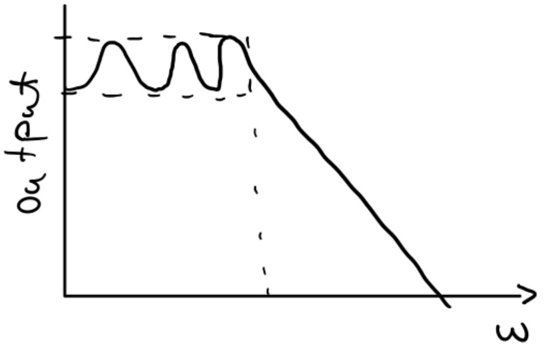

Image 8: an example of ripple in a filter, for example in a Chebyshev filter.

Amplification

Most ECG and EMG signals are in milli to microvolts, so it is necessary to amplify them. Amplification will help to detect changes in the raw signal. Amplification could be implemented in software but using the analog filtering to amplify will be faster and use less processing power. If a notch filter is not used in the filtering section, one should use a differential amplifier, ideally with high input impedance and low output impedance. The differential amplifier will remove the common signals between two different EMG or ECG signals, which can reduce noise and motion artifacts from the body and remove the power line noise. The common mode rejection ratio (CMRR) indicates how well the common signals between the two inputs are eliminated. Thus, a higher CMRR is desired, but going to a higher limit may affect the out of phase parts of the signal, which is not desirable. The CMRR of the differential amplifier can range from 90dB to 120 dB. Additionally, the CMRR will degrade at higher frequencies. In our application, this will not affect us, as the highest frequency is around 500 Hz, which is relatively low.

The amplification amount will differ depending on the muscle. Smaller muscles will be activated with less stimulation. In the application of the bicep and tricep muscle, a gain of 200-500 V/V would likely be used. But for weaker signals, such as the ring finger, the gain must be much higher, such as 10000 V/V. Thus, the amplification will be designed differently depending on the purpose of the design.

The amount of amplification will also depend on the individual and would need to be able to be adjusted depending on the user. Different people will have smaller or larger electrical pulses when moving a muscle. A good way to implement this would be a modular technique, to allow different signals to go through different amounts of amplification and to allow a different user to use different amounts of amplification.

Conclusion

In order to get the best results of a bioelectrical signal, it is best to first filter and condition it in analog before converting it to a digital signal. This allows one to detect the desired signal and be able to analyze it properly. In the case of EMG and ECG, it is important to consider how the data is being used in order to determine the best filtering scheme and the amount of amplification necessary. For our application, it is desirable to amplify it between 200 and 500 V/V. Due to the different necessities in patients, it is required that some amplification be in the software such that it can be tailored to an individual.

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