Basics of Electromyography Recording and Evaluation

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1. Introduction

Research on human motion analysis is currently getting popular in a variety of domains, including robotics applications for enhancing human-robot interaction and controlling robots to move more like humans. Muscle contractions produce the forces that propel our entire bodies during human motor control. The method of electromyography is used to gauge muscle activation. It's crucial to comprehend the electromyography mechanism when creating new technologies for neurorehabilitation[1]. The HAL exoskeleton, which is powered by muscle biosignals to support our bodily control, is one well-known example.

Electromyography is becoming more and more widespread, especially for powering robotic devices. Learning the fundamentals of electromyography and researching human motor control are therefore necessary. Through experiments of balance control in standing conditions, this experiment attempts to comprehend techniques of measuring and interpreting the electrical activity of the muscles and their relations to our joint forces.

2. Principles

2.1. Electromyography

The action potential produced when muscles contract is known as myoelectricity, and it may be measured and recorded using electromyography (EMG). The quantitative acquisition of a biological signal for the production of human motion is made possible by myoelectricity [1].

EMG signals can serve as a representation of the entry of a muscle model since they carry valuable information regarding muscle activation. In fact, the key benefit of using EMG is that it can take into account each subject's unique pattern of activation to estimate muscle force, as illustrated in Figure 1. Here, the signal starts out with a modest amplitude and grows to disclose the individual action potentials connected to each muscle fiber's contractile activity. More muscle fibers are engaged, and their firing rate increases, as the force produced of the muscle contraction rises.

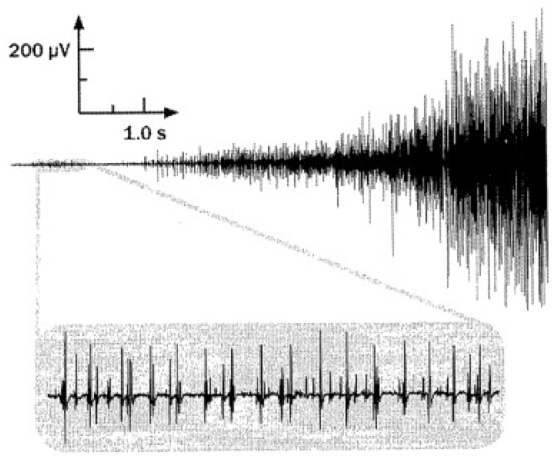

Figure 1. The EMG signal recorded with surface electrodes located on the skin above the first dorsal interosseous muscle in the hand. The signal increases in amplitude as the force produced by the muscle increases.

2.2. Experimental Signal Acquisition and Processing

Figure 2 displays a block schematic of each of the main components of the signal acquisition process. Keep in mind the many physical characteristics that filter the EMG signal before it can be detected. The group of signals coming from the surface of the muscle fibers is referred to as the "physiological EMG signal." These signals cannot be observed [1].

By placing an electrode with only one detection surface on the muscle surface and measuring the electrical potential at this point in relation to a "reference" electrode placed in an environment that is either electrically silent or includes electrical signals unrelated to those being detected, it is possible to simply obtain the electrical activity on the muscle surface. As may be seen in Figure 3(a), such a configuration is known as monopolar. The disadvantage of the monopolar design is that all electrical signals close to the detecting surface will be picked up, including undesired signals from sources other than the target muscle.

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Theme 5 Report on *Laboratory Experiment II* which was done on October 28th, 2022.

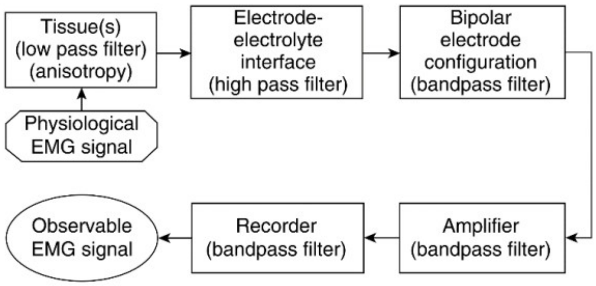
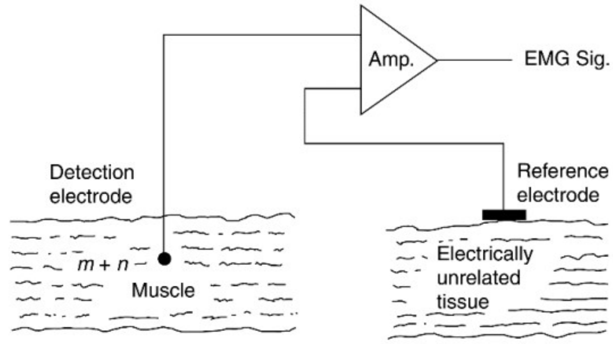
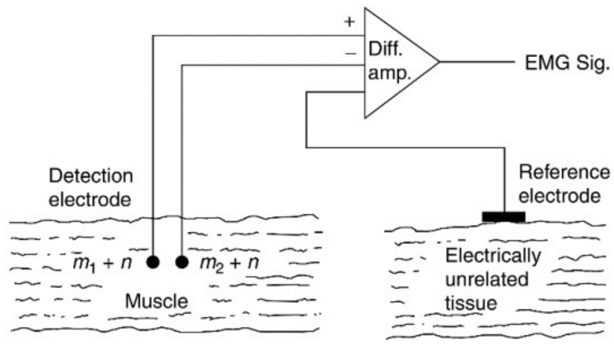


Figure 2. Block diagram of all the major aspects of the signal acquisition procedure.



(a) Monopolar detection arrangement



(b) Bipolar detection arrangement

This restriction is eliminated by the bipolar detection arrangement (see Figure 3(b)). In this instance, two surfaces are employed to detect two potentials, one with regard to the reference electrode and the other with respect to the muscle tissue of interest. The "common mode" components in the two signals are then removed by feeding the two signals into a differential amplifier, which amplifies the difference between the two signals. Because of the localized electrochemical events taking place in the contracting muscle fibers close to the detection surface, signals coming from the muscle tissue of interest near the detection surface will differ at each detection surface, in contrast to "ac noise" signals coming from a more distant source (such as 50 or 60 Hz electromagnetic signals emanating from power cords, outlets, and electrical devices) and "dc noise" signals (such as polarization potentials in the metal electrolyte junction). Therefore, in a bipolar setup, the common noise can be eliminated by subtraction.

2.3. Antigravity Muscle

Antigravity muscles are those that help human stay upright. The term "primary postural muscles" refers to a collection of antigravity muscles that specifically function to preserve posture. On the dorsal side (i.e., the backside) are all of the major muscles of posture. In this experiment, we examined three leg muscles, as shown in figure . The first is the *tibialis anterior*; the leg muscle used to lift a toe up. The second and third muscles are the medial head of the *gastrocnemius* and *soleus*, which are used to lift a heel up [2].

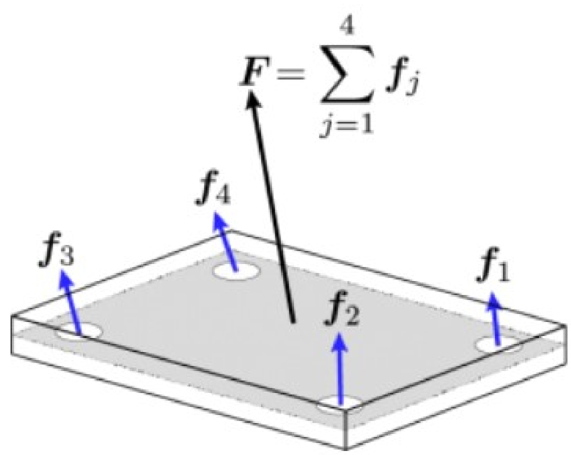
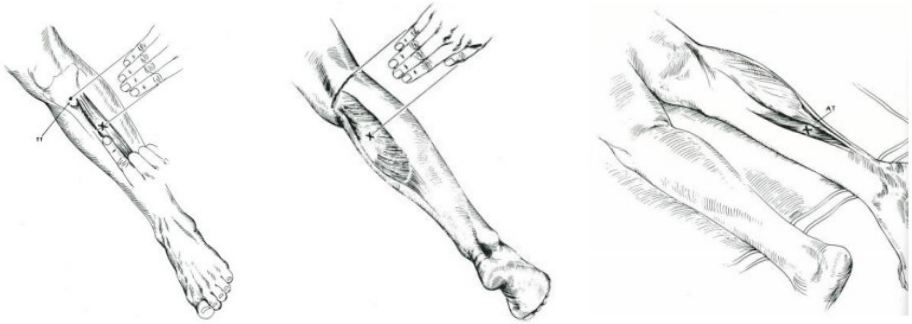


Figure 3. Plate Force Principle

2.4. Ground Reaction Force

The reaction force we experience from the ground is known as ground reaction force (GRF) [2]. With the aid of a device called Force Plate, this variable can be measured. By tracking the center of gravity's movement throughout various maneuvers, it can quantify the physical consequences on the ground. Strain gauge-style load sensors are mounted in the corners of this sensor. These load sensors then enable the force plate to detect three-axis forces and determine the load and center of pressure. By computing the force balances, this instrument can also identify the moment of force and the center of pressure. Principle of this device is illustrated in Figure 3.



(a) Tibialis anterior (b) Gastrocnemius (c) Soleus

Figure 4. Muscles to be measured

3. Experiment

3.1. Apparatus

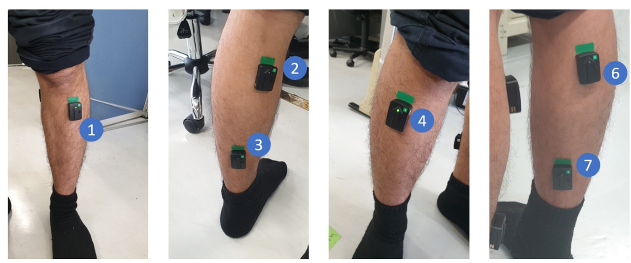
The DELSYS Trigno wireless EMG measurement equipment[3], shown in Figure 5, will be used to measure and assess EMG signals. Each EMG sensor includes a triaxial accelerometer, a battery that can be recharged for at least 7 hours, and a transmission range of 20 meters. In order to integrate with motion capture and other third-party data gathering systems, the system can stream data digitally into EMGworks®, third-party software, or via analog outputs.

We use one AMTI Force Plate [4] to measure the GRF signals. We can use this device to measure translational forces and rotational moments around the X, Y, and Z axes. It is used in this experiment to measure the activity on the floor surface caused by movement, such as extension and bending, while standing balance control is maintained using the ankle and hip joint muscles.

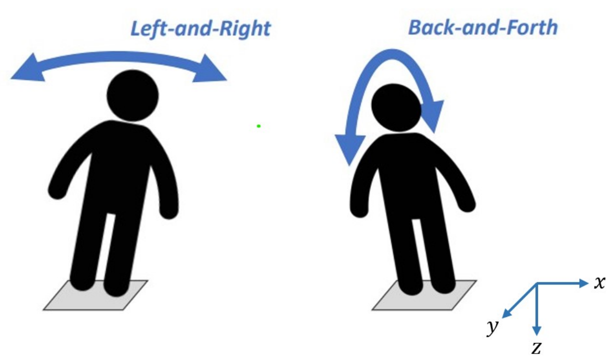
Figure 5. DELSYS Trigno wireless EMG measurement system

3.2. Procedures

The first step in this experiment is to determine the location of the desired muscles by elevating the heels and toes of the legs. A muscle location guidebook is also used to aid the determination. The EMG sensors are then attached to the muscles once they have been identified. There are six sensors in total, three on the left leg and three on the right leg. The overview of the sensor's position and the experimental procedure is depicted in Figure 6. *Note*: We skip sensor number 5 and continue from sensor number 6 to sensor number 7 [5].



(a) Location of the EMG sensors



(b) Posture movement

Figure 6. Configuration of the experiment procedures. (a) 1 & 4: *Tibialis anterior*, 2 & 6: *Gastrocnemius*, 3 & 7: *soleus*. (b) The subject's posture movement.

Following preparation, the patient is placed over the force plate, and recording is then initiated. The patient hops during the initial seconds in order for the jump signal to be recorded by the force plate and the EMG sensor (during takeoff and landing). By using this jump signal, we can synchronize the two sensors. After that, the subject alternates his posture back and forth, then left and right for approximately 90 seconds. The subject should avoid moving their arms and knees as much as possible because these movements may contribute additional moments and forces; instead, try to shift the posture only with their ankles [2].

3.3. EMG Signal Processing

The EMG signal is a time and force (and possibly other parameters) dependent signal with a random amplitude above and below zero. As a result, simple signal averaging will not provide any useful information [1].

1. *Remove the mean value from the signal*: EMG values at baseline are offset from zero. The mean (average) of the entire signal is then calculated and removed from the signal.

2. *Rectification*: The concept of rectification entails rendering only positive deflections of the signal. This can be accomplished by either eliminating (half-wave rectification) or inverting the negative values (full-wave rectification). The latter is the preferred method because it preserves all of the signal's energy.

3. Choose between:

   3.1. *Low-pass Filtering*: Frequencies below the cutoff frequency can pass through a low pass filter (i.e. higher frequencies are removed). Different physiological properties can be interpreted using the filtered EMG signal. Scientists studying muscle force and activity, for example, frequently use a low pass filter to capture the shape or "envelope" of the EMG signal, which is thought to reflect better muscle force generated by a muscle.

   3.2. *Integration*: Integration is the most commonly used data reduction procedure in electromyography. When applied to a signal processing procedure, temporal integration has a well-defined mathematical meaning. It refers to a calculation that determines the area beneath a signal or a curve. This parameter is measured in volt seconds (Vs). An observed EMG signal with a zero average value will also have a zero total area (integrated value). As a result, the integration concept can only be applied to the rectified value of the EMG signal.

$$I\{|m(t)|\} = \int_{t}^{t+T} |m(t)|dt \tag{1}$$

4. *Frequency Domain Analysis (Mean Power Frequency)*: The frequency domain analysis of the EMG signal involves measurements and parameters that describe specific aspects of the signal's frequency spectrum. Fast Fourier transform techniques are widely available and convenient for obtaining the signal's power density spectrum. Three power density spectrum parameters can be used to provide useful spectrum measures. They are the spectrum's median frequency, mean frequency, and bandwidth. Equations 2 and 3 define the median frequency and mean frequency.

$$\int_{0}^{f_med} S_m(f)df = \int_{f_med}^{\infty} S_m(f)df \tag{2}$$

$$f_{mean} = \frac{\int_0^f fS_m(f)df}{\int_0^f S_m(f)df} \tag{3}$$

where $S_m(f)$ is the power density spectrum of the EMG signal. Stulen and De Luca [6] conducted a mathematical investigation into the constraints in estimating various parameters of the power density spectrum. The median and mean frequency parameters were discovered to be the most reliable, with the median frequency being less sensitive to noise.

4. Results and Discussions

During the experiment, we conducted the signal recording two times and obtained two different sets of data. However, for this assignment, I only utilized the 1st dataset as it is considerably more reliable than the 2nd set, and basically, it has the same kind of data as the 2nd set. Furthermore, for a neater layout, all figures covered in this section (unless otherwise specified) are shown in the Appendix for each corresponding assignment.

4.1. Assignment 1

Discussion: *Filter the EMG signal data obtained in the experiment and convert it into the muscle activation data. Draw a graph of the muscle activation change with respect to the measurement time. In addition, filter the same data using different filter setting and describe the result. In particular, confirm that both low pass filtering and integration can calculate envelope of muscle activity. Consider how the setting of the cutoff frequency of low pass filtering and the time setting of integration affect the signal.*

During preprocessing, the raw data is first centralized, and after that, full-wave rectification is applied to the data. These techniques, however, are insufficient to generate useful results. This section will cover the impact of the following step, which involves smoothing by both integrating the data and low-pass filter (LPF). The outcomes of the data preparation are acquired and shown in Appendix A. In addition, data without smoothing is included for comparison.

We can see from the graphs that each smoothing technique can calculate the envelope of muscle activity. These smoothing procedures can smooth it out or make it rougher in comparison to the rectified-only signal. Additionally, a comparison between each smoothing technique is done separately. It is evident that LPF with a higher cutoff frequency results in more noise and a higher range signal. A signal that has a lower cutoff frequency is therefore more visible than one that has a higher cutoff frequency. On the other hand, an integration procedure with a large number of integral time results in a signal that is less noisy and more sterile, but less detailed. It should be noted that the integral time is determined as the product of the window size and the EMG sensor's sampling rate ($0.9\,\mathrm{ms}$/sample). Lastly, we can see that signal processed with integration that uses high integral time looks pretty similar with signal processed with LPF that uses lower cutoff frequency.

4.2. Assignment 2

Discussion: *Describe the relationship between muscle activation and floor reaction force. Consider which muscles have a large influence on posture control among the various parts where EMG signal was measured and the reasons.*

The relationship between muscle activation and floor reaction force can be drawn by analysing the signals of EMG and GRF signals. Graphs for all targeted muscles from both legs with addition X and Y axis rotational moments are depicted in Appendix B. Here, we utilize X and Y axis rotational moments as these variables are correlated with subject's posture movement. Additionally, it is worth mentioning that there is an offset time between the GRF and EMG signal, where GRF recording starts a moment ahead the EMG signal. These offset time was calculated by using scripts which will be discussed in section .

In this experiment, the subject is shifting his posture in a counte-clockwise movement. Then, the each X and Y moment can be calculated by doing cross product between the length vector of the center of mass of the subject and weight vector, which points to the z-axis. Simply put, the subject tilts backward when M_x reaches its peak, while the lowest point indicates forward motion. On the other hand, M_y attains its peak when the subject tilts to the left and vice versa.

For *Tibialis anterior*, both left and right legs' EMG signals achieves its maximum value together with the M_x value (see Figure 9(a)). This means the *Tibialis anterior* muscle contracts when tilting backward, preceded with the left leg's signal then the right leg's signal (this agrees with the counter-clockwise movement). This phenomenon also occurs when we observe the M_y the second graph (Figure 9(b)), as both legs' EMG signal reach its maximum value when the value of M_y is zero. However, this contradicts to the fact that *Tibialis anterior* becomes active when a toe is lifted. This disagreement might be caused by several reasons, such as: (1) Prior activities that might make the *Tibialis anterior* muscle to be not as active as it supposed to be. (2) There is an error on processing the data, one example is the time offset is incorrect, thus making the signals to be shifted. (3) Author makes error on doing the analysis.

For *Gastrocnemius*, the EMG signals attain their peak when the motion is shifting toward and the left-right motion: right leg for movement from back side to right side, while left leg for movement from front side to left side. This is shown from both M_x (10(a)) and M_y (10(b)) graphs. In addition, *Soleus* muscle also has the same trend but with smaller amplitude. This might indicate that both *Gastrocnemius* and *Soleus* muscles are active during heel lifting activity, but *Soleus* is less active compared to the *Gastrocnemius* muscle.

Finally, there exists a spike for all muscles in the beginning of the recording. This indicates that all muscles contract during the jumping and landing movement, where the *Tibialis anterior* is active for the jumping part and both *Gastrocnemius* and *Soleus* are active for the landing part.

4.3. Assignment 3

Discussion: *Consider about internal factors and external factors which affect the quality of EMG signal.*

We cannot ignore several factors that could still have an impact on the EMG signal's quality even when we use the most sophisticated sensors. Three groups of factors — *causative*, *intermediate*, and *deterministic* — are thought to affect the EMG signal, according to a paper written by Leading Researcher in Electrophysiology and Biomedical Engineering Carlo J. De Luca. The interrelationships of the factors, their effects on the EMG signal, and their interpretation of the signal characteristics are displayed in Figure 7. Here, we will concentrate on the *causative* factors because they have an essential or fundamental impact on the signal. Additionally, these elements are separated into two categories: intrinsic and extrinsic.

The extrinsic causative factors include those related to the electrode construction and location on the skin's surface above the muscle. They include the following:

1. Electrode configuration, which describes
    - the area and shape of the electrode detection surfaces, which determine the number of active motor units detected by virtue of the number of muscle fibers in their vicinity, and
    - the distance between the electrode detection surfaces, which determines the bandwidth of the differential electrode configuration

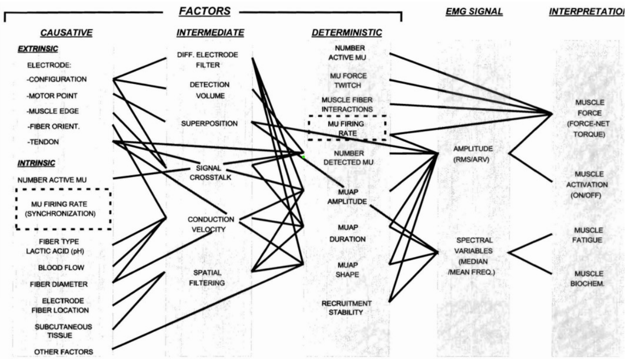


Figure 7. Schematic diagram of the factors that affect the EMG signal. The arrangement of factors is designed to demonstrate the flow of the influences and interactions among the factors.

2. Location of the electrode with respect to the motor points in the muscle and the myotendinous junction, which influences the amplitude and frequency characteristics of the detected signal.

3. Location of the electrode on the muscle surface with respect to the lateral edge of the muscle, which determines the amount of crosstalk that may be detected by the electrode.

4. Orientation of the detection surfaces with respect to the muscle fibers, which affects the value of the measured conduction velocity of the action potentials and, consequently, the amplitude and frequency content of the signal.

The intrinsic causative factors are the muscle's physiological, anatomical, and biochemical characteristics. However, unlike the extrinsic factors, they cannot be controlled due to current knowledge and technology limitations. They include the following:

- The number of active motor units at any particular time of the contraction, which contributes to the amplitude of the detected signal.

- Fiber type composition of the muscle, which determines the change in the pH of the muscle interstitial fluid during a contraction.

- Blood flow in the muscle, which determines the rate at which metabolites are removed during the contraction.

- Fiber diameter, which influences the amplitude and conduction velocity of the action potentials that constitute the signal.

- Depth and location of the active fibers within the muscle with respect to the electrode detection surfaces; this relationship determines the spatial filtering, and consequently the amplitude and frequency characteristics, of the detected signal.

- The amount of tissue between the surface of the muscle and the electrode, which affects the spatial filtering of the signal.

- Other factors that are yet to be identified, such as the length of the depolarization zone and ionic fluxes across the membrane.

4.4. Assignment 4

Discussion: *Consider how the EMG system removes the noise mixed in the EMG signal detected from the muscle of interest.*

The Delsys sensors utilized in this experiment have bipolar detection. As the action potential traverses the fiber, voltages at two electrodes spaced 1 cm cm apart align with the muscle fiber or the electrical wave. A single differential model, similar to a simple subtraction technique, is used in the signal processing, i.e., signal at electrode A minus signal at electrode B. Because the voltage from the action potential varies as it travels along the muscle fiber, the electrical signal recorded from both electrodes at any given time will be different. Consider the electrical noise produced by the testing room's main power supply (lights or *Wi-Fi* signals). This waveform would be recorded by each electrode, but because the signal is the same distance from each electrode, the signals are nearly similar — hence the subtraction cancels out the distant signal.

4.5. Assignment 5

Discussion: *Compute Mean Power Frequency on measured EMG with Frequency analysis method.*

The graphs for mean power frequences of each muscle are shown in Figure 12. We can see that *Tibialis anterior* is tend to be more dense and enclose higher range than the *Gastrocnemius* and *Soleus* muscles. Moreover, right leg's muscles are also more dense than the right leg's muscles.

	Left	Right
Tibialis anterior	134.01	128.34
Gastrocnemius	111.59	144.01
Soleus	115.47	137.75

Table 1. Mean power frequency of each EMG sensors.

4.6. Optional Assignment

Discussion: *As the EMG signal and the ground reaction forces are measured at different timing, time synchronization* *is necessary for quantitative evaluation of the relationship between them. Thus, you must implement a code that detects the moment of jumping in both the EMG signal and the ground reaction force. Also, you must implement a code that shows the EMG signal in the horizontal axis and the ground reaction force in the vertical axis. Submit both the results and the scripts.*

For this assignment, the script I made is based on the *plot_-both.py* script. For scatter plotting, I first combine the EMG and GRF data using pandas *pd.merge_asof* [7] function. This function does left join and takes two pandas dataframe, a column name to join on, and direction to search whether for prior, subsequent, or closest matches as the parameters. For the plot shown in Figure 13 , I use the direction='nearest', so that the timestamp in GRF data will search for the closest timestamp in EMG data. However, the direction can be changed in the *scatter_plot* function.

For determining the time offset, I basically just subtract the time between the time where the value of EMG and GRF are maximum (the spike). Here, I use the F_z signal as it indicates the vertival force applied to the plate. The result varies depend on the EMG signal used, but it has average of $9.0\,\mathrm{s}$, thus I utilize this value for the previous assignment. However, there is a flaw in this approach as for EMG#1 case the spike does not occur on the beginning of recording, resulting the time offset to deviate significantly.

References

[1] Carlo De Luca. "Electromyography". In: *Encyclopedia of Medical Devices and Instrumentation*. John Wiley Sons, Ltd, 2006, pp. 98–109. DOI: https://doi.org/10.1002/0471732877.emd097 (see pp. 1, 4).

[2] Kyo Kutsuzawa. *Theme 5: Basics of Electromyography recording and evaluation*. 2022. URL: https://drive.google.com/file/d/1zVTTYLuJgbiAWLN8FacKzzOi-dGagbNX/view (see pp. 2, 4).

[3] *DELSYS Trigno Wireless EMG Measurement System*. URL: https://delsys.com/trigno/ (see p. 3).

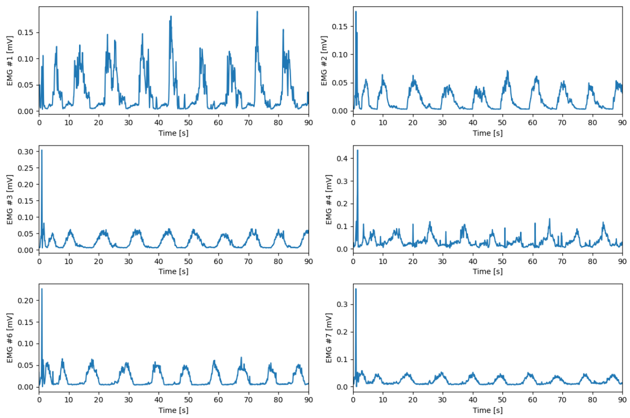
[4] *AMTI Force Plate*. URL: https://www.amti.biz/product-line/force-plates/ (see p. 3).

[5] Kyo Kutsuzawa. "Basics of Electromyography recording and evaluation". In: 2022. URL: https://drive.google.com/file/d/13OmII0PewS2rClFegvlGrZfhL2iiJWxJ/view (see p. 3).

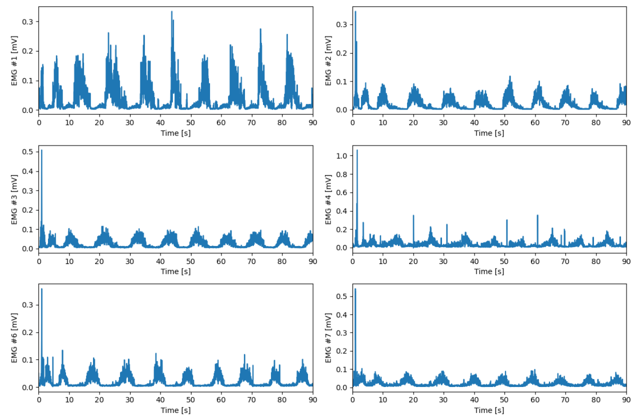
[6] Foster B. Stulen and Carlo J. De Luca. "Frequency Parameters of the Myoelectric Signal as a Measure of Muscle Conduction Velocity". In: *IEEE Transactions on Biomedical Engineering* (1981), pp. 515–523. DOI: 10.1109/TBME.1981.324738 (see p. 4).

[7] *pandas.merge_asof*. URL: https://pandas.pydata.org/pandas-docs/version/0.25.0/reference/api/pandas.merge_asof.html (see p. 7).

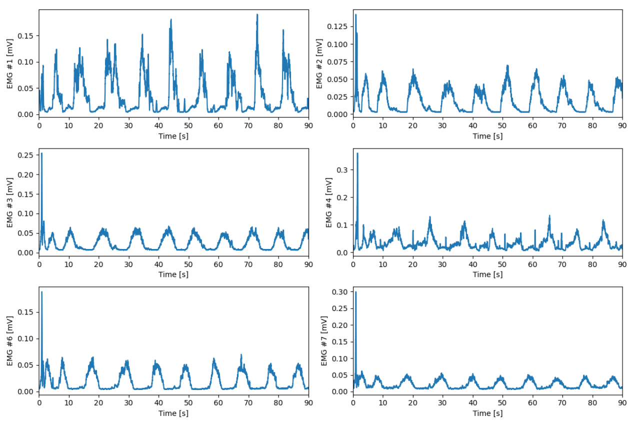
A. Result on Assignment 1



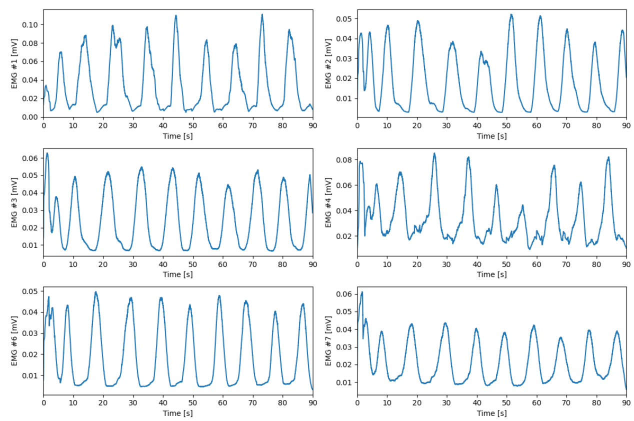
(a) LPF with cutoff frequency of 4 Hz



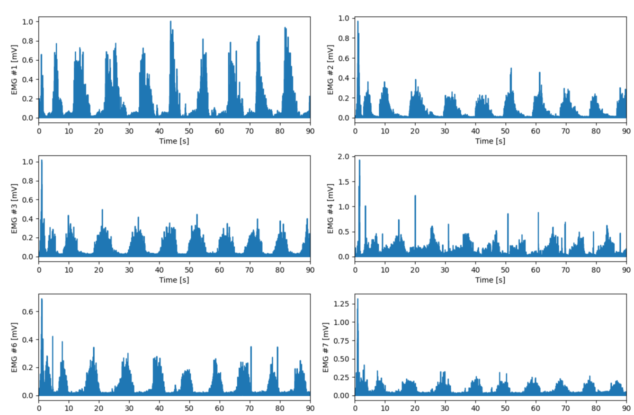
(b) LPF with cutoff frequency of 24 Hz



(c) Integration with window size of 200 samples



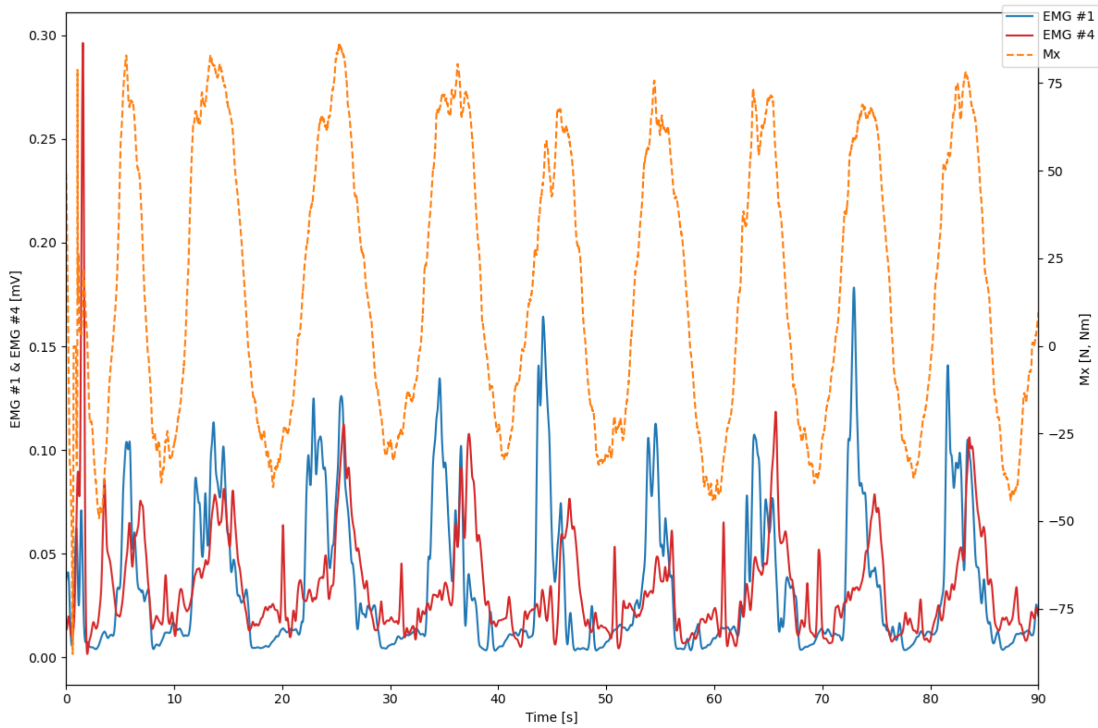
(d) Integration with window size of 2000 samples



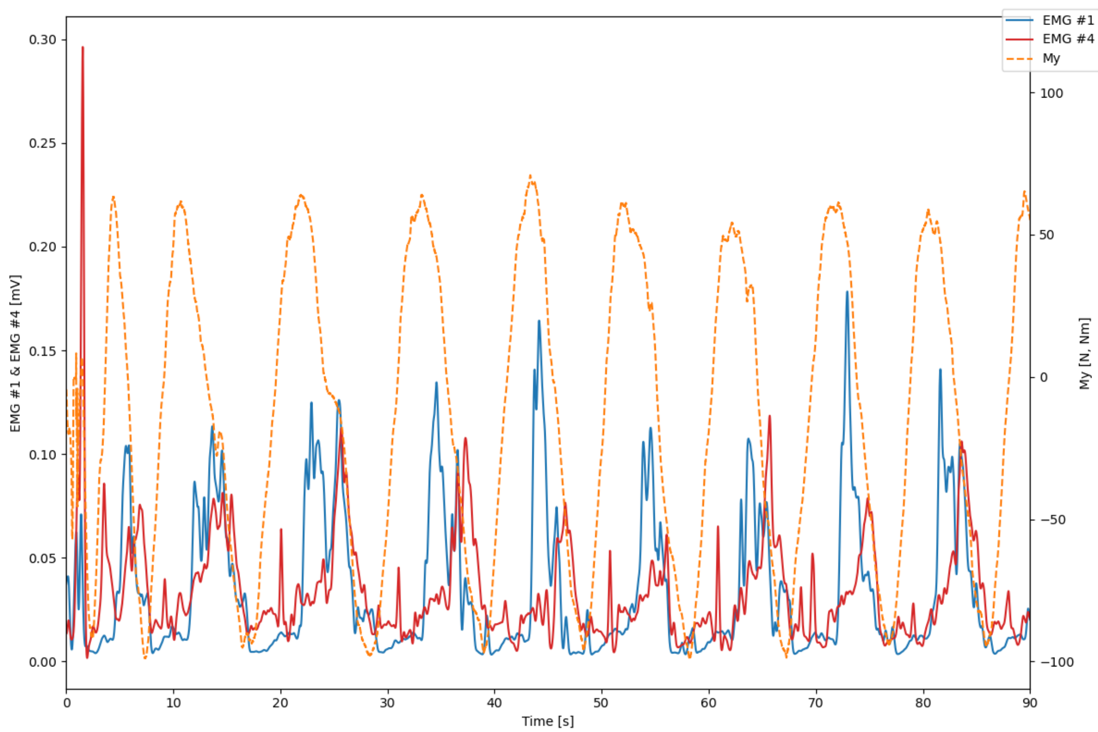
(e) Rectified (without smoothing)

Figure 8. Results of different smoothing method: low-pass filtering (8(a) and 8(b)) and integration (8(c) and 8(d)). Time interval used for plotting is between 0 s to 90 s.

B. Result on Assignment 2

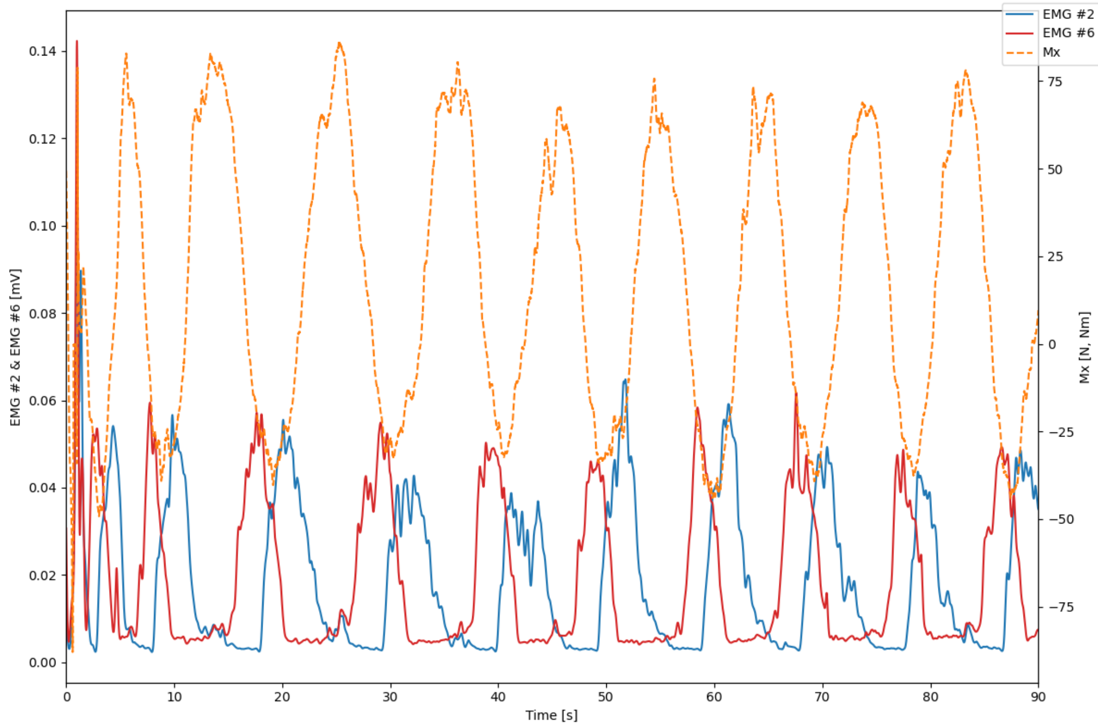


(a) Plot of EMG#1 and EMG#4 signals with X rotational moment

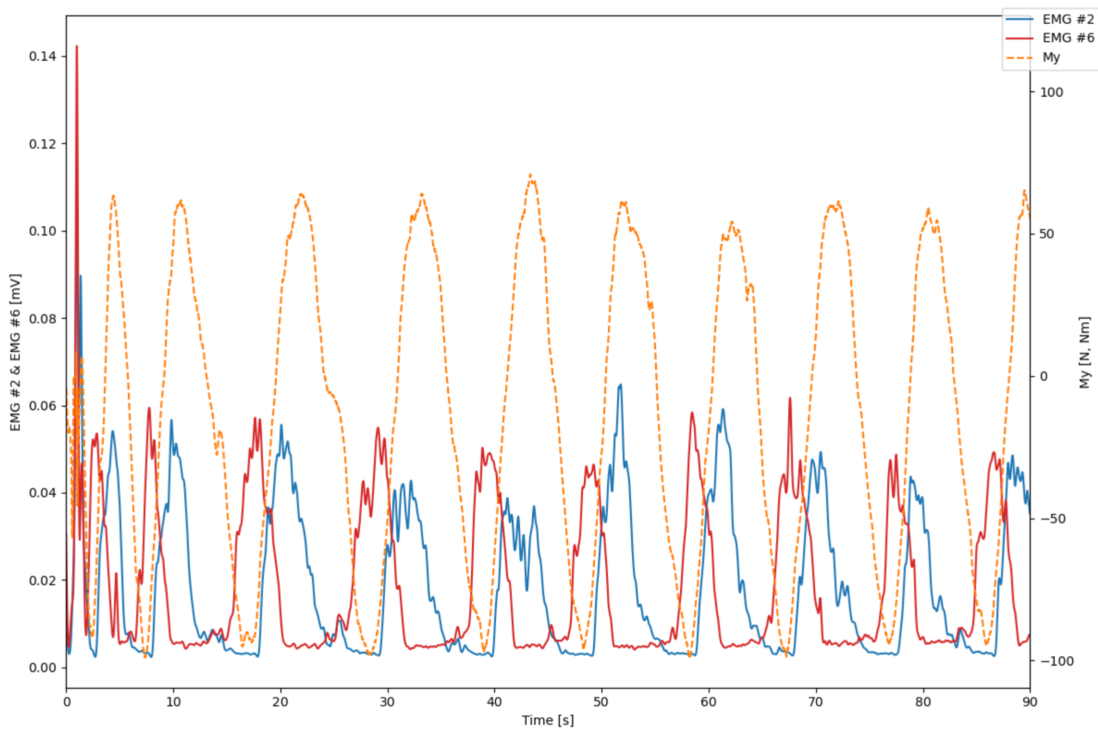


(b) Plot of EMG#1 and EMG#4 signals with Y rotational moment

Figure 9. Plot of EMG signal of right (#4) and left (#1) legs' *tibialis anterior* with X and Y rotational movement of the force plate.

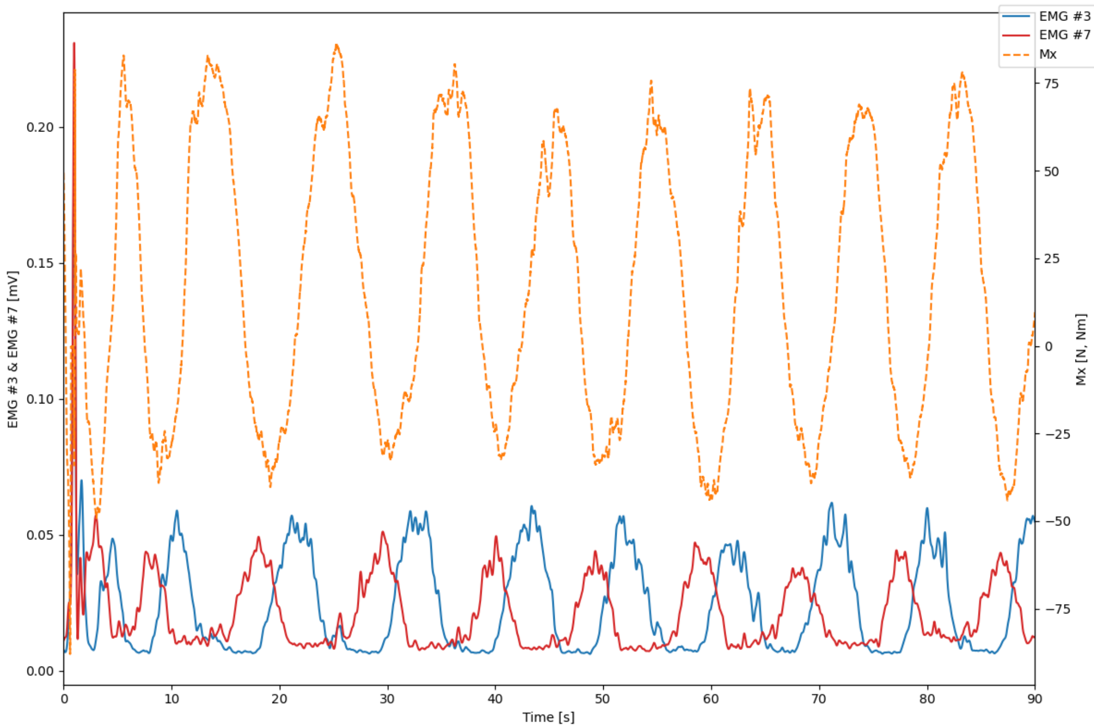


(a) Plot of EMG#2 and EMG#6 signals with X rotational moment

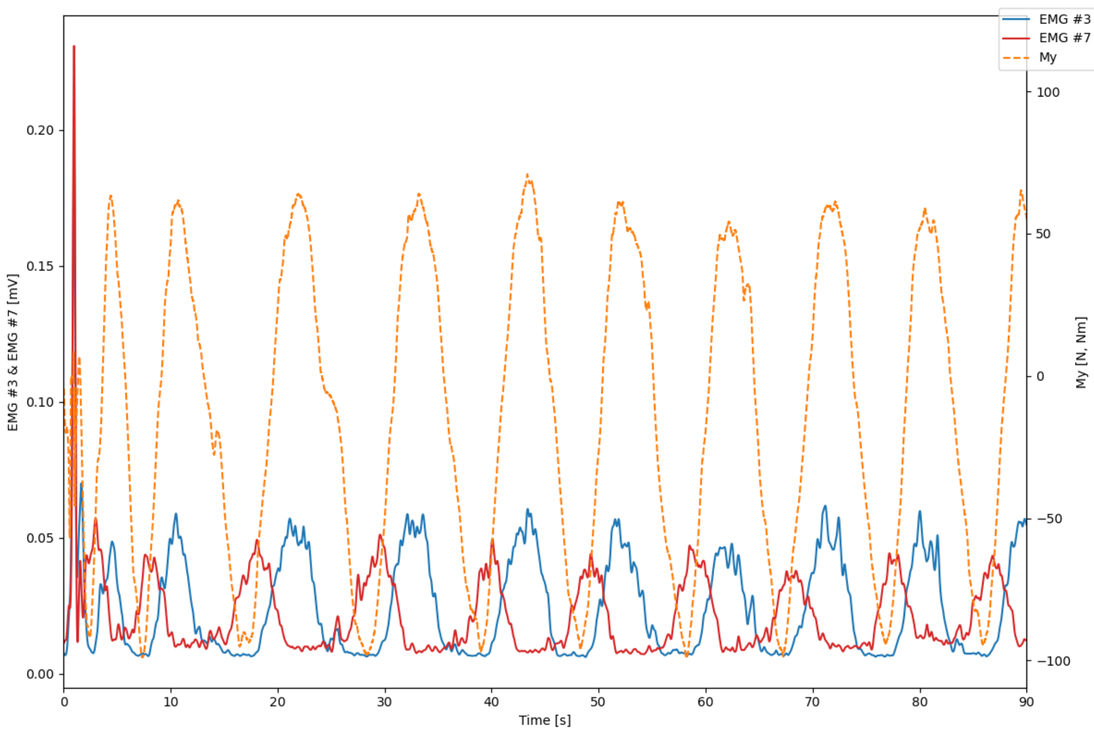


(b) Plot of EMG#2 and EMG#6 signals with Y rotational moment

Figure 10. Plot of EMG signal of right (#6) and left (#2) legs' *gastrocnemius* with X and Y rotational movement of the force plate.



(a) Plot of EMG#3 and EMG#7 signals with X rotational moment



(b) Plot of EMG#3 and EMG#7 signals with Y rotational moment

Figure 11. Plot of EMG signal of right (#7) and left (#3) legs' *soleus* with X and Y rotational movement of the force plate.

C. Result on Assignment 3

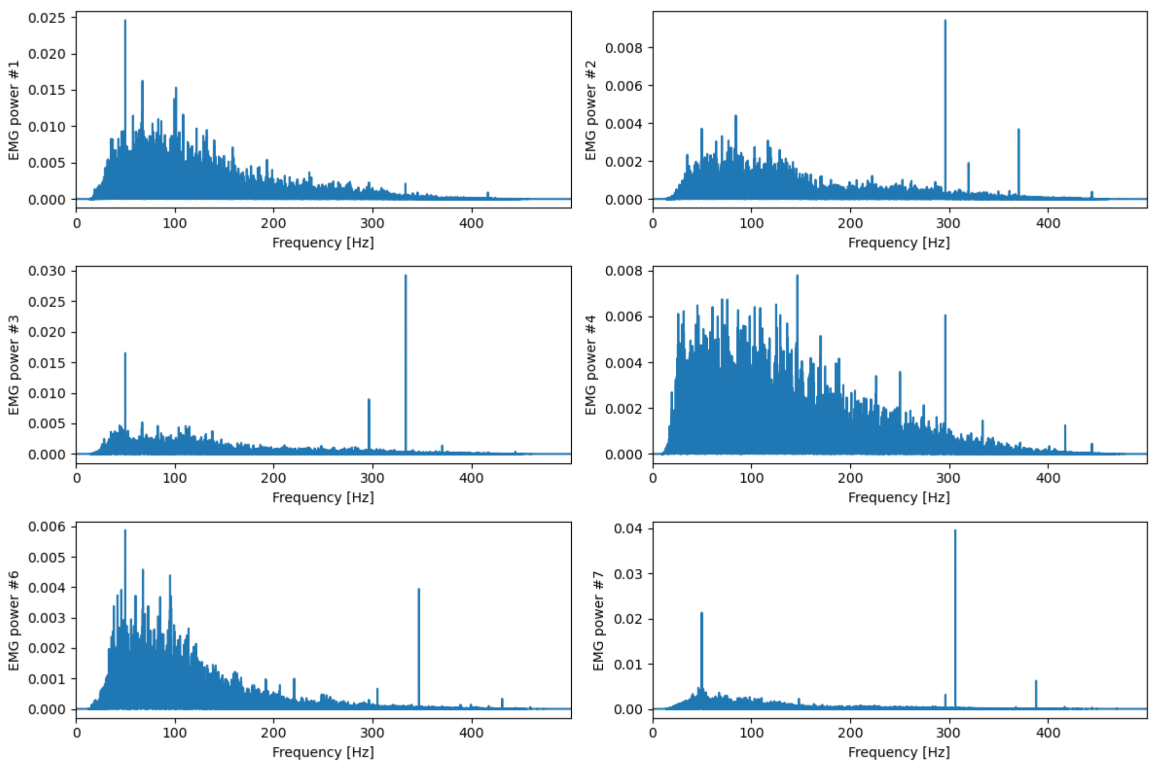


Figure 12. Mean power frequencies for each muscle.

D. Result on Optional Assignment

Figure 13. Power scatter of each EMG with GRF