SSY081 project

Instructions

- You work in groups of 4 and write a common report
- The report should be written in English (use the template)
- Each group has to submit report, code, and filled checklist through Canvas as separate files, not a zip-file
- Please indicate your group ID in the report
- It is very useful to implement the project during the course, because it helps to understand the course content. However, we are aware this is not always possible, therefore…
- There are three deadlines for report submission (18th of October, 3rd of January, 22nd of August)
- If you submit by the 18th of October, the project discussion is scheduled in the period 21st to 30th of October (time slots are available on the Canvas calendar. Please book one)
- During the project discussion, we will discuss about what you have done in the project and how it relates to what we have studied in the course
- You do not need to prepare any slide for the oral presentation. We will ask questions depending on your report/code
- Each team member is supposed to be able to justify the choices made in the project implementation and to "defend" their solution
- The grade (UG) is individual
- It may happen that there is something to be changed in the report/code. You will be granted 10 days to implement the changes

Introduction

You have learned in the course that systems can be used to model biological systems.

In this project, you will learn how to model an electromyographic (EMG) signal recorded with intramuscular electrodes (electrodes placed within a muscle).

A muscle is composed by several functional units called motor units. Each of these units, when activated, discharges a series of electrical pulses (spikes), known as action potentials. We refer to the series of action potential produced by a motor unit as action potential train. If we place an electrode within a muscle (intramuscular EMG) or on the skin overlying the muscle (surface EMG), we can record the electrical activity produced by that muscle, which is the sum of the action potential trains of the units that are active. You can read more about this topic here The Pop and Color of Our Electrified Muscles · Frontiers for Young Minds (frontiersin.org).

In this project, we have considered an experimentally recorded signal (obtained from emglab.net) and "split" the signal into the trains of action potentials. This process is known as decomposition, and for the purpose of the project implementation, there is no need to know how the decomposition works. In brief, it is a reverse-engineering process that allows us to decompose the EMG signals into the contribution of individual motor units.

In the project, you will be provided with the waveforms of 8 action potentials and, for each of them, also a sequence of the instants the action potentials occur. Your role is to combine them to generate the EMG.

Let's us provide you with more details.

Graphically, we can represent the EMG as the sum of trains of action potentials (Figure 1).

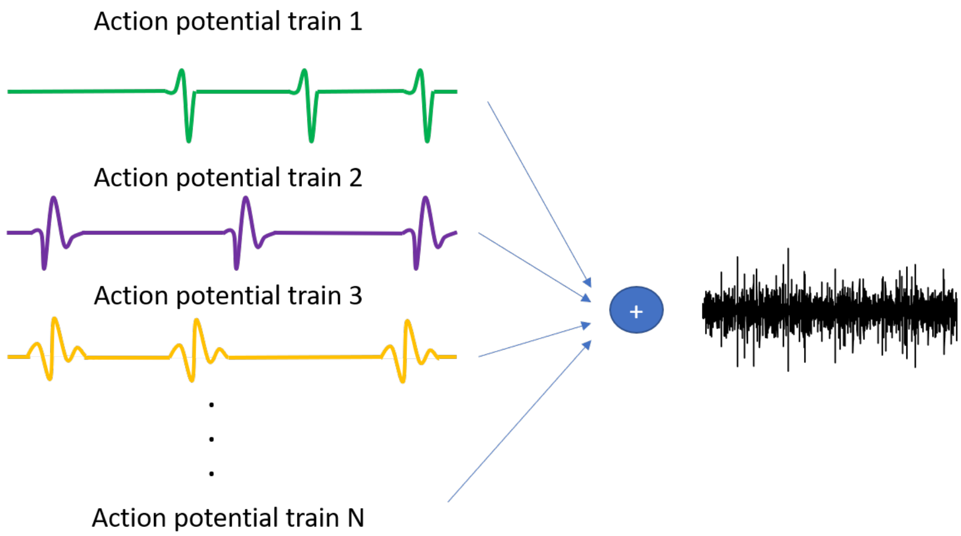

Figure 1 Generation of the EMG signal.

In Figure 1, we have considered 3 action potentials, represented in Figure 2.

Figure 2 Action potentials.

In each train of action potentials, the same action potential is repeated several times (only three times in Figure 1 for simplicity).

We can indicate with t11, t12, t13, … the time instants at which action potential 1 is discharged. The corresponding samples are s11, s12, s13, … This is represented in Figure 3.

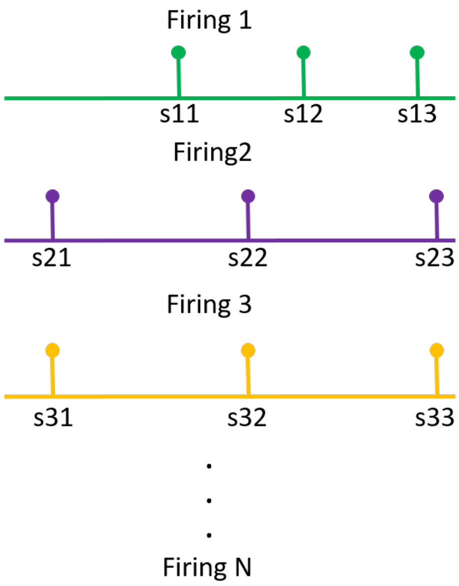

Figure 3 Firings of the action potentials represented in Figure 2.

Assignment

Please read the assignment and then the checklist and finally the assignment once more, before starting implementing the project. In this way, you (hopefully) do not have to implement changes at the end, when you read the checklist.

You are supposed to create an EMG signal composed by 8 action potential trains.

The signal duration should be 20 s, the sampling frequency 10,000 Hz.

We provide you two NumPy array files:

- action_potentials.npy
  It is a 8x100 matrix that contains the action potentials of 8 motor units.
  The number of rows (8) is the number of motor units.
  The number of columns (100) is the number of samples.
- firing_samples.npy
  It is composed by 8 cells, one for each motor unit. Each cell is a vector that contains the index of the samples at which the discharges of action potentials occur. Note that the number of discharges is different for the different units.

Below is a basic list of Python libraries than can be used for the project. We assume you use the latest version of each package. Note that you are allowed to use other libraries if you want to. If using other libraries or older versions of the listed libraries, please clarify this in your code.

- Math
- Matplotlib
- NumPy
- OS
- SciPy

Question 1.

a) Create the trains of action potentials corresponding to each unit (8 trains in total).

   Hint:

   First step, for each action potential train, you can create a binary vector with samples equal to 1 in correspondence of the firings and 0 otherwise (you are supposed to simulate 20 s of signal).

   Second step, you need to have a replica of the action potential in correspondence of each firing time. How can you obtain that?

   Describe the procedure you have followed to create the trains.

b) Explain why you have followed the procedure in question 1a. We expect a well-reasoned answer based on the theories discussed in class.

c) How many samples does each action potential train contain? Why? Is the number of samples you obtained compatible with the procedure you have followed to create the trains of action potentials? We expect a well-reasoned answer based on the theories discussed in class.

d) Plot 1 of the 8 action potential trains as a function of time (that means you should have time, rather than samples in the horizontal axis). In addition, plot the same action potential train in the time interval 10-10.5 s.

   Note: To facilitate visualization, we suggest using a line thickness of 0.5. All axes must be labelled. The unit for the time axis should be s (seconds); the unit for the amplitude of the action potentials is not provided and you should indicate A.U. (which stands for arbitrary unit). That means that the label for the horizontal axis should be Time [s]. Use analog notation for the vertical axis and for all figures in the report.

e) Comment on the procedure you have followed to obtain the proper time axis. Which is the distance between two samples? We expect a well-reasoned answer based on the theories discussed in class. Note, we are not asking details about the Python implementation, we will look at that in the code. We want to know how you established the correspondence between each sample number and the time instant corresponding to that sample number.

f) Sum the 8 action potential trains to obtain the EMG signal. Plot the EMG signal as function of time (in the time interval 10-10.5 s).

Question 2.

a) Filter the 8 binary vectors with samples equal to 1 in correspondence of the firing times. You should use a filter with impulse response equal to a Hanning window of duration 1 s (the Python function for creating the Hanning window with NumPy is “hanning”). Describe the procedure you have followed to filter the binary vectors.

b) Explain why you have followed the procedure in question 2a. We expect a well-reasoned answer based on the theories discussed in class.

c) Plot the 8 filtered signals as a function of time, in seconds (all in the same graph).

d) Create another figure where you plot the fourth binary vector and the corresponding filtered version obtained in a). Describe the filter characteristics (e.g., low-pass, high-pass). We expect a well-reasoned answer based on the theories discussed in class.

e) Create another figure where you plot the seventh binary vector and the corresponding filtered version obtained in question 2a). Compare this figure to the previous one (question 2d). Which unit fires faster (4 or 7)?

f) Why is this unit firing faster? Did you reach that conclusion looking at the binary vectors or their filtered version? We expect a well-reasoned answer based on the theories discussed in class.

Question 3.

An EMG signal can also be recorded with surface electrodes (electrodes placed on the skin overlying a muscle). Often, some powerline interference, with the fundamental component of 50 Hz/60 Hz and its harmonics, is also recorded, due to the equipment being connected to the electrical grid. The powerline interference is one of the most disturbing noise sources in biopotential recordings. In this exercise, you will simulate the presence of the power line interference in an EMG signal.

You are provided with a (simulated) surface EMG signal sampled at 1024 Hz (please load the NumPy array file *f.npy*) and code (*fft_example.py*) that reproduces the example 5.6 at page 292 of your textbook (see also Figure 5.15 of the textbook). That example was presented during the lecture dedicated to the FFT.

You are asked to

a) Simulate the presence of a power line interference at 50 Hz in the signal, without harmonics. Consider a peak-to-peak amplitude of 0.3 for the interference.
   Plot the signal corrupted by the interference and the interference-free signal on top (note: this is important) in the time domain in different colours.
b) What can you observe from the plot in question 3a?
c) Plot the absolute value of the DFT of the signal corrupted by the interference. Plot the absolute value of the DFT of the interference-free signal on top (note: this is important) with a different colour. You have to plot half of the period of the DFT (axes should be labelled, you can used A.U. for the vertical axis).
d) Explain how you created the frequency axis in question 2c. We expect a well-reasoned answer based on the theories discussed in class.
e) Comment on what you can observe from the plot in question 2c. In case you cannot observe any difference between the two plots, increase the value of the peak-to-peak amplitude of the interference signal to 0.4, 0.5, etc until you can observe a difference.

You are supposed to provide

1. A report (pdf file) that contains the replies to all the above questions (figures and comments on how you achieved the results). The report should not exceed 6 A4 pages.
2. The Python code (one file main.py with the solution to questions 1 and 2, one file mainQ3.py with the solution to question 3. No need to upload action_potentials.npy, firing_samples.npy, f.npy). Note: when we run the Python scripts, we should be able to see all figures you included in the report without modifying the scripts.
3. Filled checklist (pdf file).