EE-379K/385V

Neural Engineering - Spring 2023

ECE Department, The University of Texas at Austin

HW-1
Analysis of Peripheral Nerve Signals

Out: Wednesday, January 25, 2023 *Due: Wednesday, February 15, 2023*

Note-1: Please start early! We will hold QA sessions on Wednesdays before Feb 15^{th} in which you can ask questions ****after**** *you have started on your HW and tried as many questions as possible.*

Note-2: Group discussions with your classmates are encouraged, but you have to submit your own individual work! Make sure to analyze the results you report and to suggest ways of improvement to the applied methods!

1 Overview

In this HW, you will analyze peripheral nerve signals (PNSs) recorded through cuff electrodes from a rat's sciatic nerve. When used for recording, cuff electrodes can capture sensory afferents in response to external stimuli. You will investigate the possibility of discriminating the afferents of three different sensory stimuli from PNSs.

Details about data acquisition and experimental setup can be found in [1]. The provided dataset has three PNS recordings: each of which was acquired while the rat was in an anesthetized resting state with intermittent application of one of the following stimuli:

- **VF**: mechanical stimulus of the plantar skin using a Von Frey (VF) filament
- **Flex**: proprioceptive stimulus provoked by passively flexing the toes
- **Pinch**: nociceptive stimulus provoked by pinching the toes using fine forceps

The stimuli were specifically chosen to target three different functional groups of afferent nerve fibers: tactile mechanoreceptive, proprioceptive, and nociceptive [1].

1.1 Data Description

You will be provided with the following in the "data.mat" file:

- fs: sampling rate
- VF: data for the mechincal stimulation case
  - VF.signal: contains the time series for the VF/rest condition
  - VF.trigger: contains the labels for data points (=0 for rest, $\neq 0$ for stimulation)
- Flex: data for the proprioceptive stimulation case
  - Flex.signal: contains the time series for the Flex/rest condition
  - Flex.trigger: contains the labels for data points (=0 for rest, $\neq 0$ for stimulation)
- Pinch: data for the nociceptive stimulation case
  - Pinch.signal: contains the time series for the Pinch/rest condition
  - Pinch.trigger: contains the labels for data points (=0 for rest, $\neq 0$ for stimulation)

2 Tasks

2.1 Pre-processing: use raw signals

a) Understanding the Signals

- Import and plot the raw signals with the labels of the stimuli locations (x-axis in seconds).
- In one figure, plot the power spectral density (PSD) estimates for the Rest, VF, Flex, and Pinch periods (x-axis in Hz). *Hint: use the c1_dataVis.m MATLAB script.*

b) Bandpass Filtering

- What frequency range seems most relevant for the discrimination between the different stimuli and Rest periods? Choose the same frequency band as in [1] to bandpass filter the signals. How is filtering useful?
- Plot and compare the signals for VF stimulation before and after filtering. What differences do you observe, and how can you explain that in relation to the PSD plots before and after filtering.

2.2 Feature Extraction: use filtered signals

a) MAV and VAR features

- Implement the mean absolute value (MAV) and variance unbiased estimator (VAR) features described in [1] and defined below in eq. 1. *Hint: use the c2_featureExtraction.m MATLAB script.*
- Compute and plot the features for each of the provided signals while varying the window size (WSize: 50,100,300ms) and the percentage of overlap between windows (Olap: 0,0.25,0.75). Your plots should also include labels for stimulation intervals.
- Decide on the best values for WSize and Olap by visual inspection of the plots. Can you suggest a better approach for optimizing those two variables? Are there any considerations to keep in mind while setting the WSize and Olap?
- Discuss the quality of the MAV and VAR features in discriminating between the Rest periods and each of the Stimuli periods: VF, Flex, and Pinch.

b) Feature Selection: Use WSize = 100ms and Olap = 0

We would like to determine which of the two features is better in discriminating between each of the stimuli and Rest.

- Implement the SNR metric of [1] as defined in eq. 2 for each of the classes: VF, Flex, and Pinch: Which feature would you choose for classification.
- The SNR values for the same feature are different among the classes: which of the classes would you expect to be the easiest to detect using a classifier? Is there a physiological basis to that? *Hint: the paper can come in handy!*
- Bonus: implement a measure of descriminability of your choice and evaluate it for Rest Vs Stimulus and Stimulus Vs Stimulus combinations.

$$\begin{aligned} MAV &= \frac{1}{N}\sum_{1}^{N}|x_i| \\ VAR &= \frac{1}{N}\sum_{1}^{N}(x_i-\bar{x})^2 \end{aligned} \tag{1}$$

$$SNR_{dB} = 20 \cdot log_{10}\frac{mean(MAV_{Stimulus})}{mean(MAV_{Rest})} \tag{2}$$

2.3 Classification: WSize = 100ms , Olap =0

- Build a classifier based on each of the two features separately to discriminate Rest versus Stimulus (VF, Flex, & Pinch) and Stimulus versus Stimulus combinations. Find the 10-fold cross validation accuracy of each of the classifiers and construct their confusion matrices to answer the following: *Hint: use the c3_classification.m MATLAB script*
- Is it possible to classify all the stimuli against Rest? Is it possible to classify the stimuli from one another? Observe the confusion matrices for the classifiers and comment on the balance of classification rates for the different classes? Which of the stimuli is easiest to detect? Is your answer consistent with the psd plots of Part-2.1 and the SNR values of Part-2.2?
- Which of the two features resulted in a higher accuracy? Is this consistent with your findings in Part-2.2?
- In the previous parts, you were accessing the models/classifiers using k-fold cross validation: Does the split of the data into training and testing sets follow a certain structure or is it random (check in c3_classification.m)? Do you think such split would lead to a fair assessment of your classifier's generalization ability? why?
- Bonus: Build two classifiers: each with one of the features to discriminate all four classes at once (Rest, VF, Flex, & Pinch). Comment on the results.
- Bonus: Try combining both features to build a new 4-class classifier? Does the performance improve? How do you explain this?

References

[1] S. Raspopovic, J. Carpaneto, E. Udina, X. Navarro, and S. Micera, "On the identification of sensory information from mixed nerves by using single-channel cuff electrodes," Journal of NeuroEngineering and Rehabilitation, vol. 7, no. 1, p. 17, 2010/04/27 2010.