521273S Biosignal Processing I

Assignment 5. Analysis of the Relationship between EMG Signal Properties and Muscular Force

Deadline: Friday November 30th at 10.00

Learning outcome

After this assignment student can

- characterize the level of activity in EMG signals.
- analyze the relationship between EMG signal properties and muscular force.

In order to pass the assignment, all correctly executed task results must be personally presented to a course assistant during the scheduled laboratory consulting hours.

Background

Read chapter 5 from the course book.
Participate in the lecture on Tuesday November 27th.

The EMG signal is the electrical signal associated with muscular contraction. Level of activity of the EMG signal increases with force; see *Section 1.2.4* of the course book for details on the EMG signal. In this lab assignment, you will explore several measures, features, properties, or in other words *parameters* derived from EMG signals, and study their relationship to the associated muscular force.

The dynamic range (DR) of a signal is the difference between its maximum and minimum values over a specified duration. This range of values is also referred to as the peak-to-peak swing or range.

The average power of a signal is provided by the mean-squared (MS) value over a specified duration of time; the average magnitude over the same duration is given by the root-mean-squared (RMS) value. With the mean of the EMG signal being zero, the RMS value is equal to the standard deviation of the signal.

An approximate indicator of the level of activity in a signal is given by the number of times the signal crosses the zero line (assuming a mean value of zero; if the mean is not zero, it should be subtracted from the signal). A zero crossing is said to occur when the sign of a sample of the signal is different from the sign of the preceding sample. The average number of zero crossings over a certain time period is known as the zero-crossing rate (ZCR). It is expected that increased presence of high-frequency components in a signal will lead to larger ZCR. See *Section 5.6* on statistical analysis of EMG signals.

Turns count (TC) is the number of times the signal amplitude changes direction. In Willison method (used in this assignment) turns greater than 100 μV are counted, with the threshold selected to avoid counting insignificant fluctuations due to noise. TCR (Turns Count Rate) is the turns count divided by the time duration of the segment.

This lab exercise is based on the material provided in http://people.ucalgary.ca/~ranga/.
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In order to investigate the relationship between an independent variable and a dependent variable, it is common practice to fit a mathematical function or curve to the data samples available and examine the accuracy of the underlying model (goodness of fit). In the present lab assignment, you will investigate the appropriateness of linear fits (straight-line or linear models) to represent the variation of each parameter (DR, MS, ZCR or TCR) as a function of independent variable force.

Data

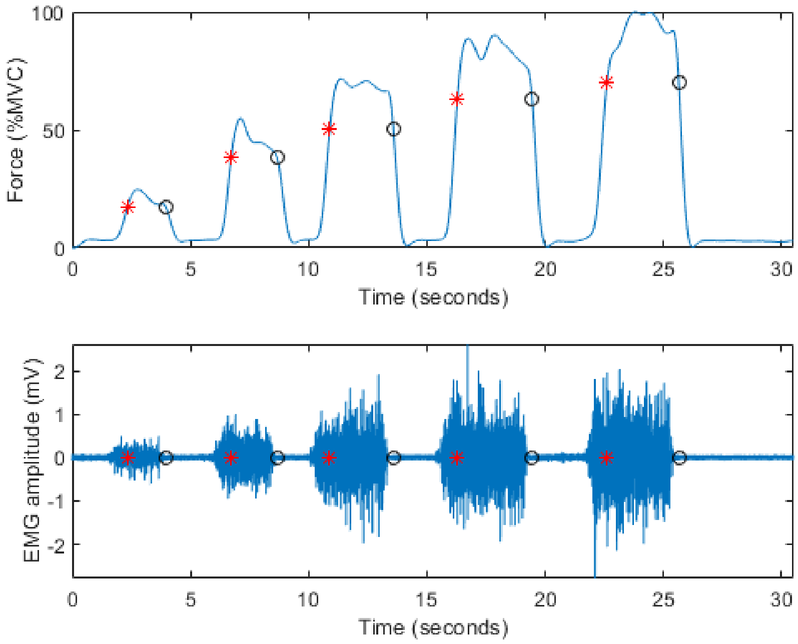

Figure 1: Muscle force and EMG signals of the experiment with segment starting and ending points marked with red stars and black circles, respectively. %MVC: percent of maximal voluntary contraction

Muscle force and EMG data from the original experiment are shown in Figure 1. The sampling rate is 2000 Hz for all provided signals, and the EMG sample values are in mV. The data segments have been prepared for the assignment and are available in `data.mat` file. The segments were cropped at their 70% of maximal value within the segment. The `data` variable is a `1x5 struct` (for the 5 segments), and has the following fields:

- `t`: the time points for the segment
- `force`: muscle force data readily prepared in percent of maximal voluntary contraction
- `EMG`: the EMG data for the segment with its mean (DC) subtracted
- `length`: the number of samples in the segment

You can reach the data with the following syntax: for example `data(2).force` is the force signal from the second segment, `data(5).EMG` is the EMG signal of the fifth segment, and so on.

Useful MATLAB commands:

`hold, max, min, diff, sign, abs, polyfit, polyval, find`

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Tasks

Write your solution as a MATLAB script (m-file)!

1. Plot all segments of the normalized force (in %MVC) to `subplot(2,1,1)`, and the EMG signal (in mV) to `subplot(2,1,2)` against their time corresponding time axes. Your plot will be like Figure 1, with the discarded signal parts (not belonging to any segment) missing from the plot. Hint: you can plot the 5 segments with separate plot signals (using `hold on`), and keep the segments in their default colors.

2. Calculate the average force exerted within each segment of the force signal.

3. Compute the DR for each segment of the EMG signal.

4. For each segment of the EMG signal, compute MS. Ensure that the MS values are computed using the appropriate number of samples for each segment. The MS value of a signal `x` over its duration of `N` samples is the following:

$$MS = \frac{1}{N}\sum_{n=0}^{N-1} x^2(n)$$

5. For each segment of the EMG signal, compute ZCR. Ensure that you normalize ZCR to zero crossings per second by dividing the number of zero crossings by the time duration of the corresponding segment.

6. For each segment of the EMG signal, compute TCR with the following algorithm.
   - Compute the derivative of the EMG signal (`diff`)
   - Detect points of change in its sign (`sign`)
   - A significant turn is found wherever the derivative signal changes sign (i.e. there is an extreme point in the original signal), and the original signal differs by at least 100 μV between current and previous (significant or non-significant) turn points
   - TCR is the amount of significant turns divided by the time duration of the corresponding segment

7. Plot the DR, MS, ZCR, and TR parameters (y axis) versus the average force in %MVC (x axis) as points (stars or circles) into four separate plots in the same figure (`subplot(2,2,n)`). In each plot, there should be as many points as there are segments. Label the axes with the appropriate units and parameters.

8. Using the `polyfit` and `polyval` functions in MATLAB, obtain a straight-line (linear) fit to represent the variation of each EMG parameter as a function of independent variable force. Superimpose the obtained linear models (straight-line fits) on their corresponding subplots of the preceding step.

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Hint: you are supposed to fit a linear model, with which you can estimate the different parameters (dependent variables) from the muscle force (independent variable).
The following syntax finds the polynomial `p` of order `n` to estimate `y` from `x`.

```
p = polyfit(x, y, n);
```

The estimate of `y` can be obtained with evaluating the polynomial at each point of `x`:

```
y_est = polyval(p, x)
```

For each point of `x`, we got a corresponding estimate of `y` with the polynomial order of `n`. Plotting them against each other results in a curve of polynomial order `n`.

Note: in this task we are fitting a linear model to the parameter, because they are the dependent variables in the original experiment. In real use of the EMG signal, exactly the opposite happens: we measure the EMG signal and compute its properties, which are used to estimate the muscle force, to evaluate the pathological status of the muscle.

9. Compute the correlation coefficients (`r`) for each parameter with *`corr`* function.

10. **Additional task** (if you want to do more):
    Segment the signal of the original experiment yourself.
    You can find the signals from the original experiment in the `task10` variable in the same `data.mat` file you already used.
    - Data in columns: (1) time in seconds, (2) force signal in arbitrary units, and (3) EMG signal in mV.
    - Normalize the force signal such that the minimum value is zero and the maximum value (corresponding to the Maximum Voluntary Contraction MVC) is 100.
    - Remove DC bias by subtracting the mean from EMG signal.
    - Identify the segments (for example with a threshold of 10% MVC)
    - Refine the segments, that they only contain the values above 70% of their local (within segment) maximum value.
    - Create an identical plot to Figure 1 with the identified segments.

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