521273S Biosignal Processing I

Assignment 2. Filtering of the ECG Signal for the Removal of Noise

Deadline: Friday November 9th at 10.00 am.

Learning outcomes

After this assignment student can

- remove high-frequency noise from signal
- remove low-frequency noise from signal
- remove power-line interference from signal
- describe how each filter affects in time and frequency domain

Background

Read chapter 3 from the course book.
Participate in the lecture on Tuesday November 6th

ECG signals are often contaminated with a combination of high-frequency noise, low-frequency noise (baseline wandering), and power-line interference. High-frequency noise may be removed by applying a lowpass filter and low-frequency noise may be removed by applying a highpass filter. However, improper selection of the cutoff frequencies of the filters could lead to distortions in ECG signal, such as excessive smoothing or widening of the QRS complex, and distortion of PQ and ST segments.

Data

Download the data files ***ecg_signal_1*** and ***ecg_signal_2*** from Noppa.
Their sampling rate is F_S = 1000 Hz. Design and interpret all filters with this sampling rate.

Useful MATLAB commands

`fft, filter, freqz, nextpow2, conj, ones, conv, semilogy, sgolayfilt`

Exercise

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

Plot all asked time domain signals in the same plot using subplot with 5x2 subplot matrix. Entire ECG signals are plotted on the left side (`subplot(5,2,x)`) and one cardiac cycle is plotted on the right side (`subplot(5,2,x)`). You may create the figure for time domain signals named Fig1 as: `Fig1=figure;` and `figure(Fig1)` returns the handle to the figure.

Plot all asked power spectra to the same plot using subplot with 5x1 subplot matrix. You may create the figure for power spectra named Fig2 as: `Fig2=figure;` and `figure(Fig2)` returns the handle to the figure.

Note: Ensure that the axes of the plots are labeled in suitable units such as seconds, Hertz, dB, ... However, the amplitude of the signals may be shown in arbitrary units (AU). Remember also to put titles on all plots!

Hint:

$$H(z) = \frac{Y(z)}{X(z)} = \frac{b(1) + b(2)z^{-1} + \cdots + b(nb+1)z^{-nb}}{1 + a(2)z^{-1} + \cdots + a(na+1)z^{-na}}$$

1. Plot the ***ecg_signal_1***, over the full duration and over one cardiac cycle (time interval 1.0 - 2.0 sec) to figure Fig1 (row 1).

   Plot the power spectrum of the entire ***ecg_signal_1*** to figure Fig2 (row 1).

   Power spectrum:
   first do the `fft(x,Nfft)` and the power is obtained by multiplying the Fourier transformation by its complex conjugate (*conj*):

   $$S_2(\omega) = \frac{1}{Nfft} X(\omega) * X^*(\omega)$$

   To scale the x-axis: `f=(0:(Nfft/2))*Fs/Nfft;`

   Hint: `semilogy` is handy while plotting power spectra.

2. Construct the 10-point ***moving average filter*** by constructing arrays `a` and `b` that are used with `filter` command (equations 1 and 2). Signal: ***ecg_signal_1***

   The general form of moving average filter is:

   $$y(n) = \sum_{k=0}^{N} b_k \, x(n-k) \qquad (1)$$

   Applying the z-transform, we get the transfer function H(z) of the filter as:

   $$H(z) = \frac{Y(z)}{X(z)} = \sum_{k=0}^{N-1} b_k \, z^{-k}, b_k = 1/N \qquad (2)$$

   Specify the filter in terms of the `a` and `b` arrays via the `filter` command in Matlab.

   Plot the filtered signal, over the full duration and over one cardiac cycle (time interval 1.0 - 2.0 sec) to figure Fig1 (row 2).

   Plot the power spectrum of the entire filtered signal to figure Fig2 (row 2).

   Obtain the magnitude and phase response (by using `freqz(b,a,[],Fs)`) of the filter and plot them in their own figure. (Hint: use the function without assignment to plot automatically.)

3. Construct the ***derivative based filter*** to remove low-frequency artifact (equation 3). To maintain the dynamic range of the filter and avoid overflow, normalize the filter to have a maximal gain of unity: divide the gain `b` by `real(max(freq_response))`.

$$H(z) = \frac{Y(z)}{X(z)} = \frac{1}{T}\left[\frac{1-z^{-1}}{1-0.995z^{-1}}\right] \qquad (3)$$

   Signal: ***ecg_signal_1***
   Specify the filter in terms of the `a` and `b` arrays via the `filter` command in Matlab.

   Plot the filtered signal, over the full duration and over one cardiac cycle (time interval 1.0 - 2.0 sec) to figure Fig1 (row 3).

   Plot the power spectrum of the entire filtered signal to figure Fig2 (row 3).

   Obtain the magnitude and phase response (by using `freqz`) of the filter and plot them in their own figure.

4. Construct a ***comb filter*** to remove powerline noise at 60Hz (common in the Americas and parts of Asia) by using following arrays:

```
b_comb=[0.6310 -0.2149 0.1512 -0.1288 0.1227 -0.1288 0.1512 -0.2149 0.6310];
a_comb=1;
```

   Signal: ***ecg_signal_1***
   Specify the filter in terms of the `a` and `b` arrays via the `filter` command in Matlab.

   Plot the filtered signal, over the full duration and over one cardiac cycle (time interval 1.0 - 2.0 sec) to figure Fig1 (row 4).

   Plot the power spectrum of the entire filtered signal to figure Fig2 (row 4).

   Obtain the magnitude and phase response (by using `freqz`) of the filter and plot them in their own figure.

5. Combine all three filters by convolution of corresponding `a` and `b` arrays. Use `conv` function in series which gives you the new arrays of combined filter. Apply this combined filter to ***ecg_signal_1***.

   Plot the filtered signal, over the full duration and over one cardiac cycle (time interval 1.0 - 2.0 sec) to figure Fig1 (row 5).

   Plot the power spectrum of the entire filtered signal to figure Fig2 (row 5).

   Obtain the magnitude and phase response (by using `freqz`) of the filter and plot them in their own figure.

6. Repeat steps 1-5 with the signal ***ecg_signal_2***. Use time interval 2.0 – 3.0 sec.

7. Make a short report of your results:
   - Analyze the effect of each filter in the time domain. Make use of the plots.
   - Analyze the effect of each filter in the frequency domain. Make use of the plots.
   - How do the results differ between the studied signals?

8. Additional task (if you want to do more):

   Apply Savitzky-Golay filter (`sgolayfilt`) to ***ecg_signal_1*** to remove baseline wandering. More information about S-G filter: lecture (November 6th), [1], Wikipedia, etc.

   Hint: `sgolayfilt` produces the trend signal, which has to be removed (subtracted) from the original signal.

   Try different values for parameters *k* and *f*. Try to find the best possible values for the removal of baseline wandering so that no valuable information is lost from the signal.

   Make a table about your experiments (successes and failures). The table should include parameter values used and the achieved results. Plot the best result (`subplot(3,1,x)`: original signal, output of `sgolayfilt`, filtered signal).

References

[1] Savitzky A, Golay MJE (1964) Smoothing and Differentiation of Data by Simplified Least Squares Procedures. Anal Chem 36(8):1627–1639.