521273S Biosignal Processing I

Assignment 6. Frequency-domain Analysis of Heart Sounds

Deadline: Friday 7th at 10.00

Learning outcomes

After this assignment, student can

- use spectrogram representation when doing frequency-domain analysis
- perform segmentation of phonocardiograms (PCG)
- produce an averaged Power Spectral Density (PSD) of segments of a PCG signal

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

Background

Read chapter 6 from course book.
Participate in the lecture on Tuesday, December 4th.

Phonocardiograms
A Phonocardiogram (PCG) is a recording of the heart sounds. Some of the important features of the PCG include: the frequency content of murmurs and heart sounds, the maximum intensities of the heart sounds, the intensity patterns of murmurs, and the timing sequence of the heart sounds and murmurs.

Heart sounds are caused by the acceleration or deceleration of blood in the heart's chambers. There are two major heart sounds that occur during a cardiac cycle. The first heart sound (S1) is due to ventricular contraction, and occurs at the same time as the QRS complex in the ECG signal. (See Section 1.2.8 of the course book.) The frequency content of S1 is limited to a low-frequency band of about 10-120 Hz.

The closure of the semilunar (pulmonary and aortic) valves gives rise to the second heart sound (S2). S2 occurs at about the end of the T wave in the ECG. The frequency content of S2 is usually higher than that of S1, in the range of about 10-200 Hz.

The intervals between S1 and S2 of a cardiac cycle, and between S2 of a cycle and S1 of the next cycle (corresponding to ventricular systole and diastole, respectively) are normally silent (see Fig. 1). Murmurs, caused by certain cardiovascular defects and diseases, may occur in these intervals. Murmurs are high-frequency noise-like vibrations that arise when the velocity of blood becomes high due to an irregularity, orifice, or defect through which the blood flows.

"Many pathological conditions of the cardiovascular system are reflected in heart sound signals, which makes it possible to diagnose heart disease by analyzing heart sound signals." [1] One way of analyzing heart sounds is to use a Spectrogram, which is a method to visually represent the spectrum of frequencies of signal, here PCG, as they vary within some interval of time.

This lab exercise is based on the material provided in http://people.ucalgary.ca/~ranga/enel563/.
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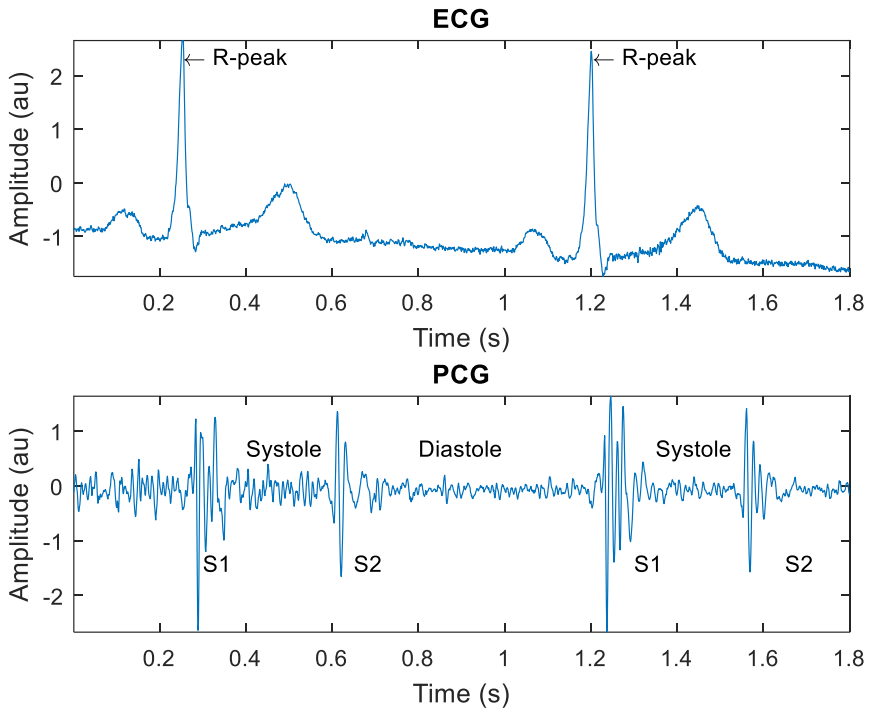

Figure 1. Simultaneously recorded ECG and PCG and the four states of the PCG recording; S1, Systole, S2 and Diastole. Systole is the part of the cardiac cycle when a heart chamber contracts.

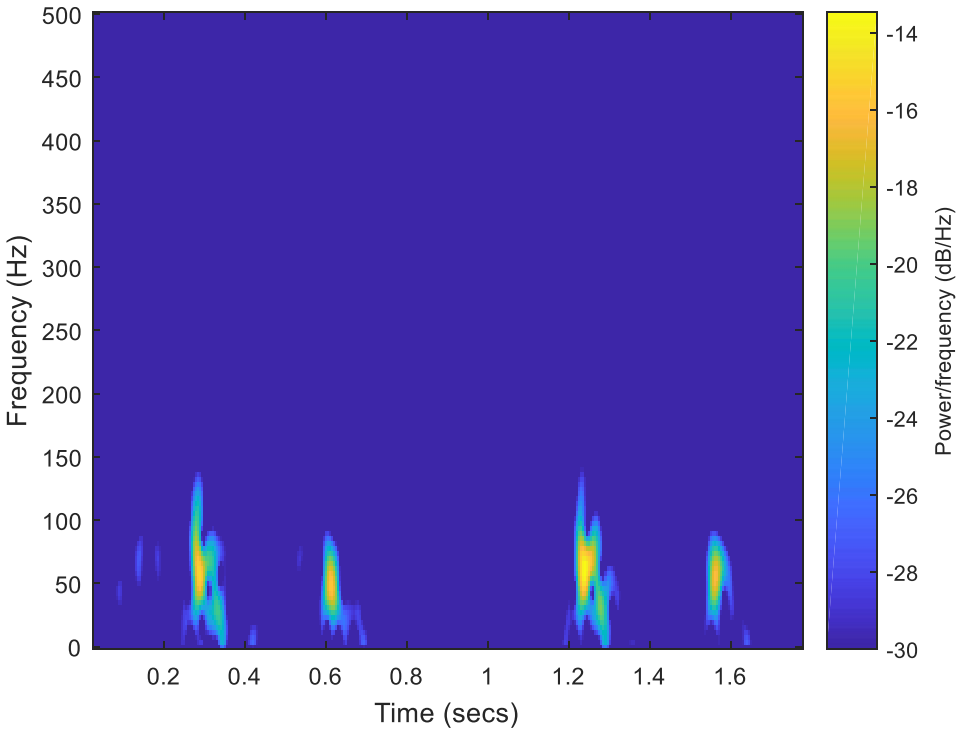

Figure 2. Spectrogram corresponding to the PCG signal in Fig. 1. Frequency is displayed on the vertical axis and time on the horizontal axis, and plot intensity as a heat map.

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Power Spectral Density

The Power Spectral Density (PSD) of a signal is given by the squared magnitude of the Fourier transform (FT) of the signal. In the case of PCGs, the random nature of the vibrations and the associated signals causes variation in the frequency content from one heart beat (cardiac cycle) to another. Therefore, the PSD computed using one PCG cycle or segment will not provide an accurate representation of the PSD of the signal. In order to overcome this limitation, we could extract PCG segments from several cardiac cycles using the ECG as a reference (trigger) signal, compute the PSD of each segment, and average the PSD's over several cardiac cycles. In such a procedure, each segment should correspond to the same phase or period of the cardiac cycle. The procedure may be applied to derive separate PSD's for the different distinct parts of the PCG signal, such as S1, the systolic segment after S1, S2, and the diastolic segment after S2 (until the next S1). The averaged PSD's may then be characterized in terms of quantitative features, such as moments. See Sections 6.4.5 and 6.6 of the course book.

Useful MATLAB commands:

load, subplot, title, xlabel, ylabel, spectrogram, resample, pwelch, mean, meanfreq, numel

Data

Use the data file `data6.mat` and function `detectPeaks.p` downloaded from Noppa.

The data is given in one file ('`data6.mat`') containing the phonocardiograms (PCG) and electrocardiograms (ECG) of all five patients. The sampling rate of the signals is 1000 Hz.

Similarly to the previous assignment, the signals are available in a `1x5 struct` (for the five patients), which has the following fields:

- `t`: the time points for the signals
- `ECG`: the ECG signal of the patient
- `PCG`: the PCG signal of the patient
- `label`: pathological information

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

The first and second signals belong to normal subjects. the third and fourth belong to two subjects with *ventricular septal defect* (a hole between the two ventricles, causing blood to leak from the left ventricle to the right ventricle during systole), causing systolic murmur in the PCG. The fifth signals are from a subject with *aortic stenosis* (stiffened leaflets of the aortic valve causing incomplete opening of the valve and constrained ejection of blood into the aorta during ventricular systole), causing systolic murmur in the PCG.

You can listen to the PCG's using the MATLAB *sound* function in case you are interested.

Tasks

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

Part 1

1. Load the signals to MATLAB workspace and set a variable for the sampling frequency f_s.

2. Plot the original ECG and PCG signals to `subplot(2,1,n)` for each patient individually. ***Hint:*** save the handles to the figures, so the plots can be used for task 5.

3. Study the Spectrograms of the PCG signals
   - Choose two complete cardiac cycles from the ECG signals for each patient. If in doubt, use the two cycles from the struct `cycles`, which is similarly structured as `data`.
   - Plot those cardiac cycles for each patient using *`subplot(3,1,1)`* command (make individual figure for each patient)
   - Plot also corresponding PCG signals for each patient using *`subplot(3,1,2)`* command
   - Plot the spectrograms corresponding to each PCG for each patient using *`subplot(3,1,3)`* command
     - Before you can do this, you need to do a test plot to determine a suitable thresholding for the spectrogram to reveal the S1 and S2 states using the first recording (same threshold is to be used with spectrograms for all 5 patients)
     - Use *`spectrogram`* function; define a window to divide the signal into sections and perform windowing, use an integer value of `50`; define the number of overlapped samples of overlap between adjoining sections, use an integer value of `45`; specify `nfft` parameter as empty (`[]`); include sampling frequency and the parameter value for `'MinThreshold'` that you obtained by looking at the spectrogram heat map; include parameter `'yaxis'`; see *`doc spectrogram`* for details.
   - What can you notice when you compare the spectrograms of different patients and knowing their background?

Part 2

4. Use the previously written function (Assignment 4) of yours (based on the Pan-Tompkins algorithm presented in Chapter 4.3.2 of the course book) along with the given black box function *`detectPeaks`* to detect QRS onsets from ECG signals.
   - `[peakOnsets, peakOffsets] = detectPeaks(data);`
   - Input:
     - `data`: the Pan-Tompkins output (after integrator) from which you want to detect the QRS complexes (at 200 Hz).
   - Output:
     - `peakOnsets`: beginnings samples of QRS complexes (delay-adjusted)
     - `peakOffsets`: ending samples of QRS complexes (not needed)
   - The sampling frequencies of the given data and with which your Pan-Tompkins algorithm works are not the same: make necessary resampling of ECG signals in your script (use `resample` function) before using codes from Assignment 4.

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- Don't forget to subtract the value of the first sample of the ECG signal from the entire ECG prior to processing by the Pan-Tompkins algorithm.
- Continue working with the original (1000 Hz) signals. You can shift the beginnings of the QRS complexes to corresponding places in the 1000Hz signal by multiplying the QRS onset values by 5.

5. Segment the systolic parts of the PCG signals by selecting a duration of 300-350 ms starting from the beginning of each QRS complex. The window should include the beginning of the S1 which is normal systolic sound occurring after the beginning of QRS complex and possible systolic murmur, but not the S2 sound which is normal diastolic sound occurring during/after T wave. You may determine the duration by visual inspection for each signal. ***Hint:*** Plotting the systolic starting and ending points on the plots from task 2 will help.

6. Compute the Power Spectral Density (PSD) for each PCG segment using the Welch's averaged Periodogram method: `[Pxx,f]=pwelch(x,[],[],[],FS)`. Furthermore, calculate the average PSD (you can use *mean* function with two parameters) and its mean frequency for each patient.
    - As a result, you should have a final figure with 15 (5x3) subplots. Each row of this figure should include following plots from each patient:
        - the first systolic PCG segment
        - PSD of this segment
        - average PSD computed using all PCG segments available
    - Compute the mean frequency of the averaged PSD for each patient (*meanfreq*).
    - What can you notice when you compare the average PSDs and mean frequencies of different patients and knowing their background?

Additional task (if you want to do more)

- Compute the mean frequency of the averaged PSD for each patient by using the equation 6.30 of the course book.
- Compute the mean frequency of the averaged PSD for each patient by using some other method.

References

[1] Zhang, W., Han, J., & Deng, S. (2017). Heart sound classification based on scaled spectrogram and partial least squares regression. Biomedical Signal Processing and Control, 32, 20-28. URL: http://www.sciencedirect.com/science/article/pii/S1746809416301616