EE512 – Applied Biomedical Signal Processing

Practical session – Time & Frequency

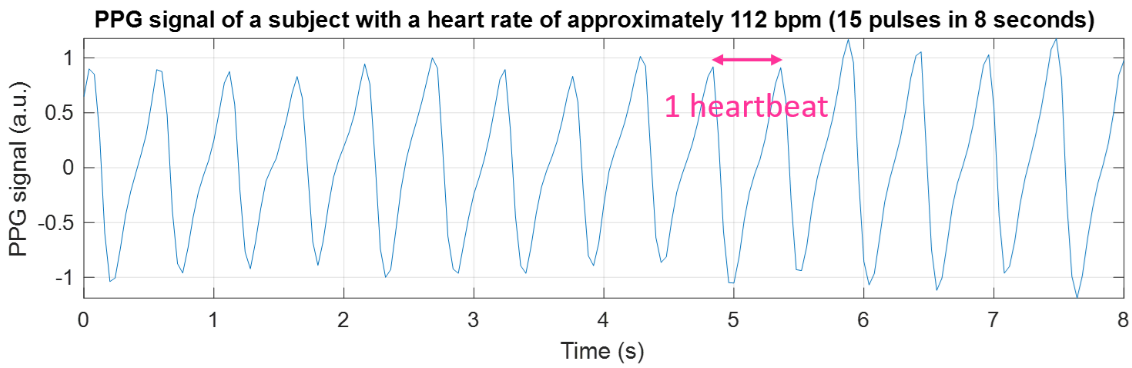
Instructions

- Please submit your report as a single PDF file.
- We recommend working in groups of 3 students; the last group can be a group of 2 or 4. You can prepare one single report for the group (`name1_name2_name3_lab_TimeFrequency.pdf`), but every member needs to upload the same file individually.
- There are 2 experiments in this practical session. The Matlab scripts for each experiment are already coded and will only require minimal inputs from you. The major part of this practical session is therefore focused on questions testing your understanding and correct interpretation of the signals and the analysis results that you see.
- The session is prepared to be done in Matlab – other languages like Python would be possible but would require you to re-code everything from scratch.

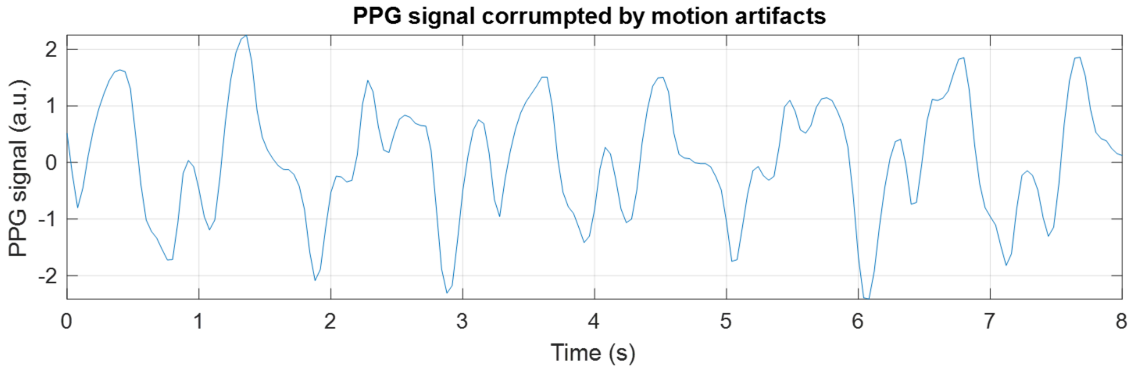
Useful commands: Type `help function_name` for more information on inputs and outputs, and `doc function_name` for a more detailed description of the function.

Experiment 1: Heart rate estimation from a smartwatch-derived PPG signal during exercise

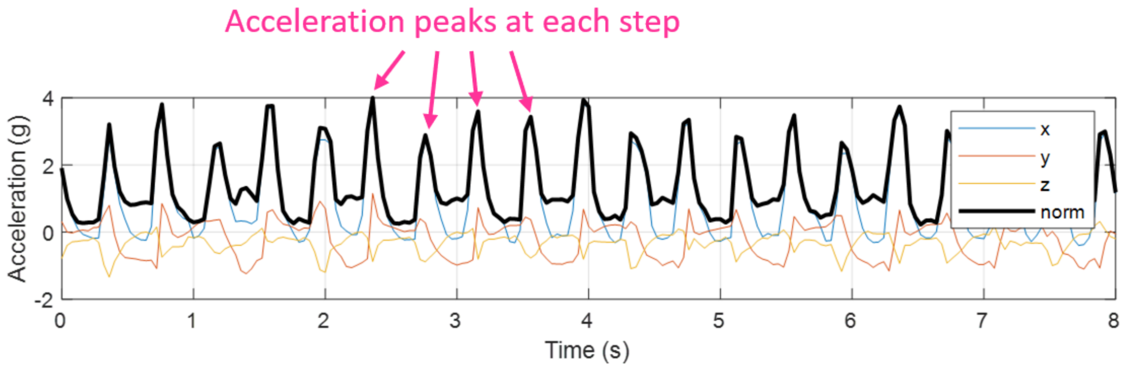
The file "ppg_acc.mat" is a recording from a smartwatch worn at the wrist by a subject during an exercise protocol. The variable `ppg` contains a photoplethysmographic (PPG) signal – or optical signal – measured by the watch by illuminating the skin with a green LED and measuring the reflected light with a photodiode. The PPG signal is affected by changes in light absorption of the skin. At each heartbeat, the small vasculature of the skin dilates and absorbs more light. The PPG signal measured by the photodiode is therefore composed of a series of small pulses corresponding to the heartbeat of the subject, as shown below.



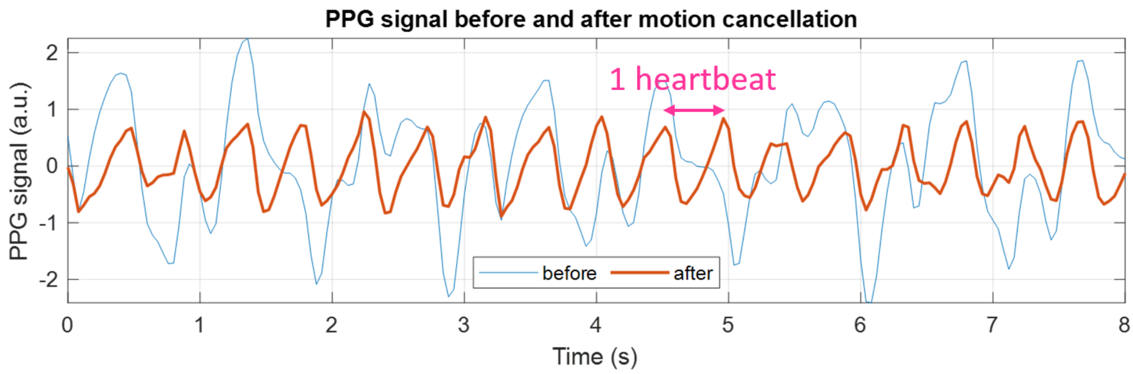
While it is easy to estimate the subject's heart rate from such a signal, it becomes more complicated when the subject is not at rest and is doing physical exercise (e.g. running). Rhythmic motion artefacts appear in the signal, making the extraction of the subject's heart rate less obvious.



The variable `accn` contains the norm of the 3-axis accelerometer signal measured by the watch. Each axis (x, y, and z) of the accelerometer measures the acceleration in a direction of space. Because space direction is quite arbitrary for a sensor worn at the wrist, considering for instance that the z-axis is 'vertical' makes little sense, and therefore considering the 3 axes separately does not bring much information, which is why it is simpler to combine them in a single signal, namely their norm ($\sqrt{acc_x^2 + acc_y^2 + acc_z^2}$), which carries all the frequencies contained in the 3 axes. See in the figure below an example while the subject is running, where the `accn` signal is dominated by acceleration peaks at each step due to the impact of the feet with the ground.



This accelerometer norm signal can typically be used to estimate the frequency of motion (and its harmonics) and to denoise the PPG signal by cancelling the motion-related components in the PPG signal, which is precisely what smartwatches do. The picture below shows the same PPG signal as above after motion cancellation, i.e. after filtering out all motion frequencies. Extraction of the heart on the filtered signal becomes feasible again.



In the recording, the protocol performed by the subject was the following (in that order): 1) walk; 2) run (slow pace); 3) run (fast pace); 4) rest (recovery); 5) bike (slow pace); 6) bike (fast pace); and 7) rest (recovery). Execute the Matlab script "experiment1.m", which will display the spectrogram of the PPG signal and the spectrogram of the accelerometer norm signal.

a) **QUESTION #1:** Using the spectrogram of the accelerometer norm signal, identify when the 6 aforementioned phases of the protocol have occurred.

b) Observe how the frequency components of motion – which are visible in the spectrogram of the accelerometer norm signal – also appear in the spectrogram of the PPG signal.

c) With that in mind, identify the two traces in the spectrogram that correspond to the heart rate and its second harmonic.

d) **QUESTION #2:** Looking at the trace of the heart rate throughout the recording, roughly estimate what is the minimal and the maximal heart rate reached by the subject during the entire protocol.

e) **QUESTION #3:** If you had not known that the biking sessions had occurred after the walking/running sessions during the protocol (and not the other way around), explain how you could have guessed that from the spectrogram of the accelerometer norm signal. (Think of how different hand motion is between running and biking and how this could translate in the accelerometer norm signal.)

f) **QUESTION #4:** Explain why motion cancellation could potentially pose a problem to estimate the heart rate at the beginning of the fast running session?

g) **QUESTION #5:** Determine at what pace (steps per minute) the subject was walking at the beginning of the recording? (Hint: read the comment in the Matlab script in the "Baseline attenuation" block, it should be helpful.)

Experiment 2: Sympathovagal balance estimation from blood pressure variability during sleep

The file "bp.mat" is a recording of the intra-arterial blood pressure of a patient with arteriosclerosis (thickening and stiffening of the arteries). The variable `bp` contains the beat-to-beat mean blood pressure of the patient over night resampled at a sampling frequency of 20 Hz. Beat-to-beat blood pressure variability is modulated in the low frequency range (LF, 0.04–0.15 Hz) mainly by sympathetic activity of the nervous system (Mayer waves), while it is modulated in the high frequency range (HF, 0.15–0.40 Hz) mainly by vagal (or parasympathetic) activity (respiratory modulation). The LF-to-HF ratio (the ratio of power between both frequency bands) is often used as a measure of the balance between sympathetic and vagal activities, called sympathovagal balance. A chronically increased sympathovagal balance is an indicator of cardiovascular and autonomic diseases.

a) The duration of the window of analysis (the `winduration` variable in the code) is currently set to an arbitrary value of 1 second.

   QUESTION #1: Change the value of `winduration` in the code ("experiment2.m") to a better suited value and explain your choice.

b) For improved readability of the spectrogram, the lower limit of the color map should be adapted to a higher value (the `cmaplowlim` variable in the code).

   QUESTION #2: Change the value of `cmaplowlim` in the code to a better suited value and explain your choice.

c) **QUESTION #3:** Looking at the spectrogram, how does the sympathovagal balance compare between the 3 following time points: t = 2 hours, t = 4 hours, and t = 6 hours? (No need to calculate anything, simply explain where the balance is the highest/lowest and how you concluded that from the spectrogram.)

d) Inspect visually the time signal approximately ±3 minutes around the three time points mentioned above.

   QUESTION #4: Could you have concluded the same without the spectrogram, by simply looking at the time signal?

Have a good session, and don't hesitate to ask questions!