```
clear;
close all;
clc;
```

## Load the raw data

```
load('ppg_acc.mat');
```

## Baseline attenuation: Highpass filter on the PPG and accelerometer signals

For the PPG signal we do not want to filter out the heart rate. Considering a minimal physiological heart rate of 30 bpm (0.5 Hz), we can use a highpass filter at 0.5 Hz. For the accelerometer norm signal, we do not want to filter out the frequencies of rhythmic motion. Considering a very slow walking pace of 1 step/s (1 Hz), the frequency of the arm swinging movement is half of that frequency, i.e. 0.5 Hz, and therefore we can use the same filter as for the PPG signal.

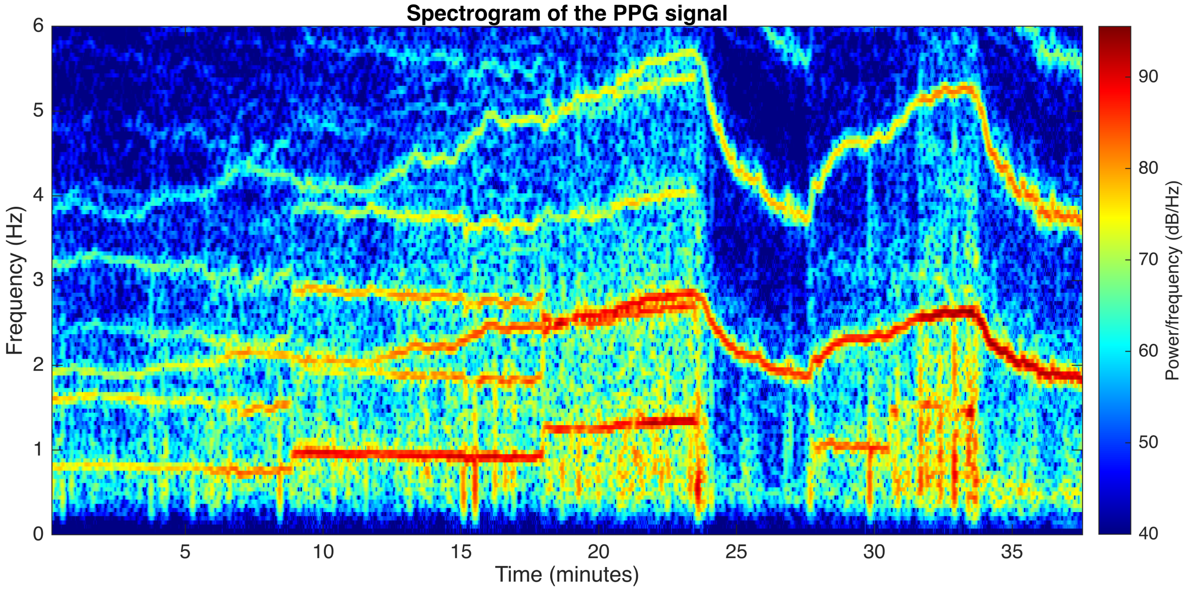
```
fs = 25;
[b,a] = butter(2, 0.5/(fs/2), 'high');
ppg = filtfilt(b, a, ppg);
accn = filtfilt(b, a, accn);
```

## Spectrogram of the PPG & accelerometer norm signals

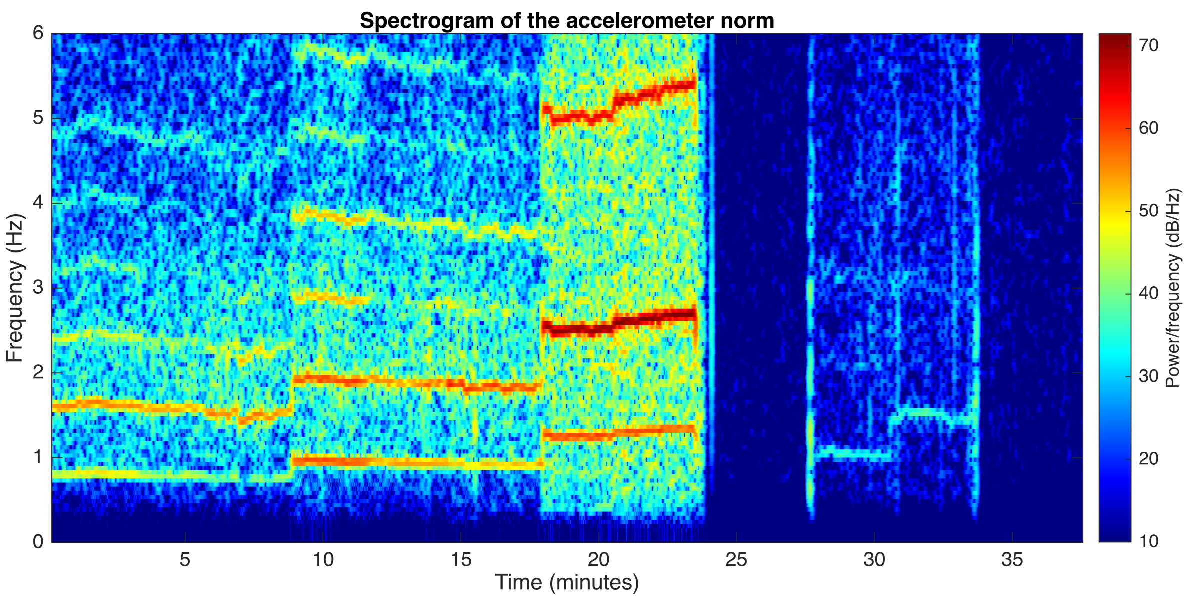
When running, or when suddenly stopping an intense exercise, the heart rate can change quite fast in matter of a few seconds. A window of 10 seconds would be short enough at all times to consider the signal stationary in the window. However, a slightly longer window, e.g. 20 seconds, will also be fine the vast majority of the time, with the advantage of improving the frequency resolution of our spectrogram. It is therefore a good choice.

```
window = round(20*fs);          % Windows of 20 seconds
noverlap = round(0.95*20*fs);   % Overlap of 95%

figure('Units','centimeters','Position',[0,0,25,11],'Color','w');
spectrogram(ppg, window, noverlap, [], fs, 'yaxis');
ylim([0,6]);
colormap('jet');
set(gca, 'clim', [40, max(get(gca, 'clim'))]);
title('Spectrogram of the PPG signal');
```




```
figure('Units','centimeters','Position',[5,5,25,11],'Color','w');
spectrogram(accn, window, noverlap, [], fs, 'yaxis');
ylim([0,6]);
colormap('jet');
set(gca, 'clim', [10, max(get(gca, 'clim'))]);
title('Spectrogram of the accelerometer norm');
```




## Question 1:

The 7 phases of the protocol take place as follows:

1) walk for the first 9 seconds (T=0 to 9s)

2) run (slow pace) for 9 seconds (T=9 to 18s)

3) run (fast pace) for 6 seconds (T=18 to 24s)

4) rest (recovery) for 3 seconds (T=24 to 28s)

5) bike (slow pace) for 3 seconds (T=28 to 31s)

6) bike (fast pace) for 3 seconds (T=31 to 34s)

7) rest (recovery) for the the last 3.5 seconds (T=34 to 37.5s)

## Question 2:

We can observe that there is one harmonic of our PPG signal, starting at approximately 4 Hz. The fondamental starts at 2 Hz and increases up to 3 Hz. The rest is noise, caused by the movement.

## Question 3:

When biking, the hand is not moving a lot compared to running. Hence we expect the accelerometer norm signal to have less energy during biking sessions compared to running sessions. The accelerometer spectrogram indeed reveals this contrast.

## Question 4

During the fast running session, the heart rate has a frequency close to the harmonics of the movement. Therefore, trying to remove the signal of the accelerometer by applying a notch filter will also remove the signal of interest.

## Question 5

On the spectrogram of the accelerometer norm, one can read a frequency of 0.8Hz, which corresponds to 48*2 = 96 steps per minute.

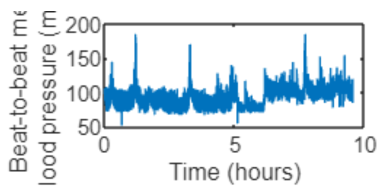
```
clear;
close all;
clc;
```

## Load the raw data

```
load('bp.mat');
```

## Plot the raw time signal

```
fs = 20;
t = (0:length(bp)-1)'/fs;
figure('Units','centimeters','Position',[0,0,25,11],'Color','w');
plot(t/3600, bp);
xlabel('Time (hours)');
ylabel({'Beat-to-beat mean','blood pressure (mmHg)'});
```




## Baseline attenuation: Highpass filter on the BP signal

The lower limit of the LF range is 0.04 Hz. With a cut-off frequency at 0.01 Hz, one can check (with the freqz function for instance) that we do not attenuate significantly any frequency component >= 0.04 Hz. Therefore, 0.01 Hz is a good trade-off between effective baseline cancellation and preservation of the frequency bands of interest.

```
[b,a] = butter(2, 0.01/(fs/2), 'high');
bp = filtfilt(b, a, bp);
```

## Spectrogram of the BP signal

Adjust the window duration below to a better value and explain your choice.

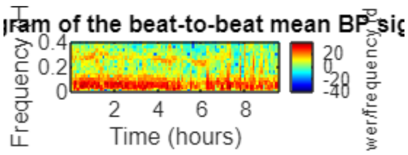
```
winduration = 2/0.04;     % Window duration in seconds: Find a better suited
value
window = round(winduration*fs);
noverlap = round(0.95*winduration*fs);  % Overlap of 95%

figure('Units','centimeters','Position',[0,0,30,11],'Color','w');
spectrogram(bp, window, noverlap, [], fs, 'yaxis');
ylim([0,0.4]);
colormap('jet');
title('Spectrogram of the beat-to-beat mean BP signal');
```

```
% Adjust the lower limit of the colormap to a better value to improve the
% readability of the spectrogram.
cmaplowlim = -40%min(get(gca, 'clim')); % Lower colormap limit: Find a
better value
```

```
cmaplowlim = -40
```

```
set(gca, 'clim', [cmaplowlim, max(get(gca, 'clim'))]);
```




### Question 1

We need a window length of at least 1/0.04 Hz = 20 s. We took the double to have some margin. However, taking a larger than necessary window length would increase the frequency resolution but decrease the time resolution.

### Question 2

We notice visually that there are no values below -40 dB/Hz. Therefore, we set the minimum value of the axis to -40 dB/Hz.

### Question 3

When looking at these 3 timepoints, we notice that:

at T = 2 h, the sympathetic activity is much stronger than the vagal activity,

at T = 4 h, the two bands are roughly the same,

and at T = 6 h, the vagal activity is slighty more intense than the sympathetic activity.

Hence the sympathovagal balance moves toward a stronger sympathetic activity over the three timepoints.

### Question 4

It is possible to notice the differences in the sympathovagal balance.

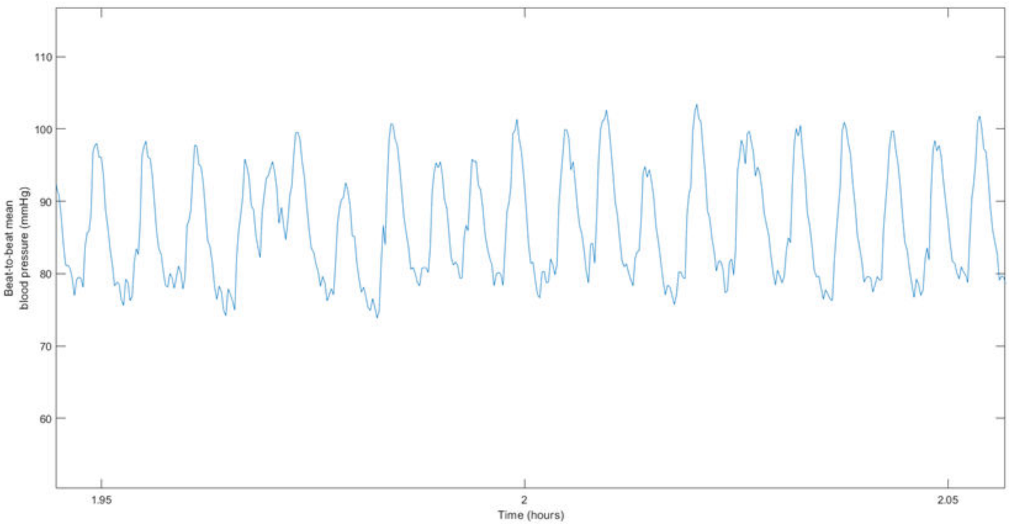
When **t = 2 hours**, we notice a dominant low frequency of the signal. Therefore, we can note the dominance of the sympathetical activity over the vagal activity ;

When **t = 4 hours**, we see a mix of both high and low frequencies, hence there is a good balance between parasympathetical and vagal activities ;

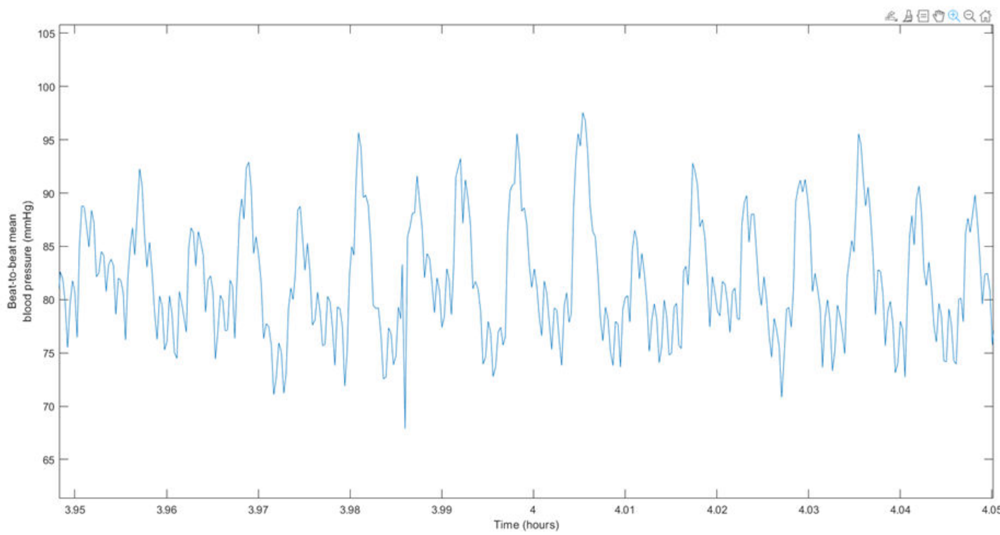
When **t = 6 hours**, we can hardly notice the low frequency in the signal, as the higher frequencies are much more dominant, from what we can deduce that there is a higher vagal activity at this time point.

Of course, it is **much easier** to draw these conclusions when looking at the spectrograms, due to the fact that this one is plotted in 2 dimensions.

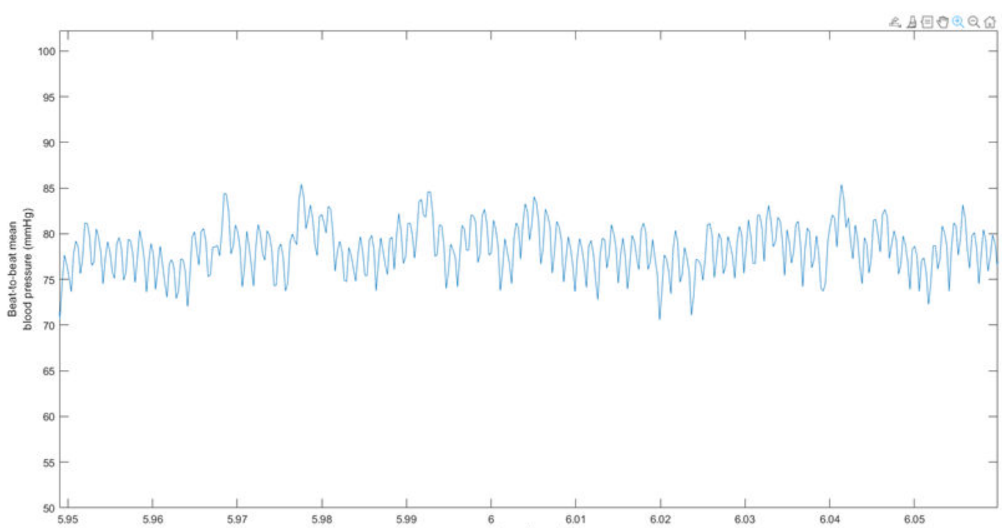
**t = 2**


110
100
90
80
70
60
Beat-to-beat mean
blood pressure (mmHg)
1.95
2
2.05
Time (hours)

**t = 4**


105
100
95
90
85
80
75
70
65
Beat-to-beat mean
blood pressure (mmHg)
3.95
3.96
3.97
3.98
3.99
4
4.01
4.02
4.03
4.04
4.05
Time (hours)

**t = 6**


100
95
90
85
80
75
70
65
60
55
50
Beat-to-beat mean
blood pressure (mmHg)
5.95
5.96
5.97
5.98
5.99
6
6.01
6.02
6.03
6.04
6.05
Time (hours)

# Exercise: Respiration signal of a patient suffering from sleep apnea

## Question 1

We know that the signal has a frequency of 8/60 = 0.133 Hz, hence a period of 7.5s. Therefore, our window length must be at least 7.5 s to capture the frequency of one cycle of the normal respiratory activity, but it needs to be shorter than 20 seconds to capture the occasional periods of apnea, where the amplitude of the signal is equal to zero.

**WL is in [7.5 , 20] s**