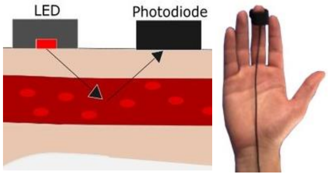
Polycardiography

Introduction

Polycardiography is a common recording of several observations of the hear cycles. Basic methods are represented by **electrocardiography (ECG)**, **pulse plethysmography (PPG)** and **phonocardiography (PCG)**, that evaluate phases of the cycle as systolic and diastolic intervals. Assessment of the polycardiography may reveal a heart weakness and risk of heart attack.



PPG – optical measurement of reflexivity (transparency) of peripheral vessels, that variate depend on actual blood pressure.

PCG – acoustic recordings of heart sounds generated by opening and closing of heart valves (heart sounds and murmurs)

Heart cycle is physiologically connected with the activity of other organs, that are regulated by sympathicus and parasympathicus. For example, inspiration increases heart rate, expiration decrease heart rate. The explanation can be more energetically effective blood oxygenation in the lungs and preserving constant cardiac output of blood during increased pressure within the chest. Change of chest impedance influence amplitude of ECG (mainly R-peaks) during breathing.

PPG reflects the continuous value of blood pressure in the bloodstream. Peaks correspond with systole, minima with diastole. Partly reflected blood pressure wave from the flexible body causes duplication of systole with local minimum called dicrotic notch. The maximal of systolic pressure is during heart contraction, which corresponds with R-peaks in ECG. The pulse wave is spreading from the heart through the bloodstream. Therefore, measured PPG on hand finger is delayed. The velocity of pulse wave reflects the condition and flexibility of vessels (slow=flexible, fast=striated, plaque). The amplitude of systole is also variated by pressure in the chest during breathing.

Heart sounds are generated by vibration of blood particles, valves and ventricle wall. The strongest are 1st and 2nd heart sound. **First heart sound** is generating by the closure of mitral and tricuspid valves after increasing of intraventricular pressure. Its duration is approximately 150 ms and follows the R-peak in ECG. **Second heart sound** is generating by the closure of aortic and pulmonary valves. Its duration is shorter (approximate 100 ms) and follows the end of T-wave.

Aims

a) Record own or use available polycardiography signal (ECG, respiration, PCG, PPG). Measure the distance from the heart to the PPG sensor.
b) Extract the parameters, that are influenced by breathing.
    a. ECG: heart rate variability (HRV)
    b. ECG: R-peak amplitude (R and S peak difference)
    c. PPG: systole amplitude
    d. Correlate parameters with chest belt breathing reference
c) Determine respiratory rate per minute from all parameters
    a. Decide, what parameters can be used to indirect respiratory measurement
d) Measure pulse wave velocity (delay between R-peaks and systoles)
e) Segments 1st and 2nd heart sound based on ECG
    a. Compute the average frequency spectrums of both sounds
    b. Compute first and second spectral moments

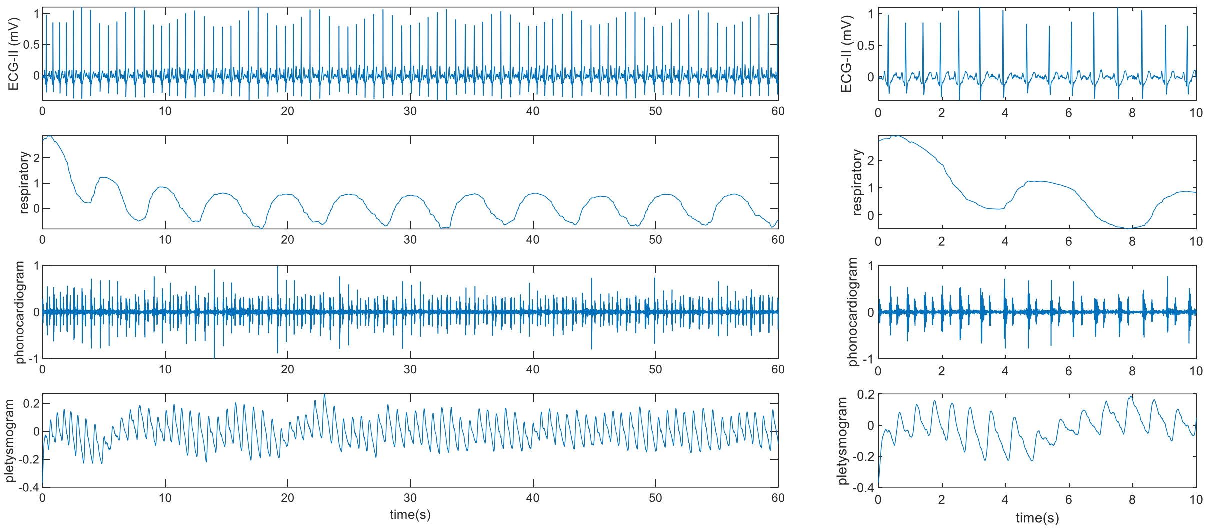
Biosignal recordings:

- Standard bipolar ECG second lead, – negative electrode on right hand, + positive electrode in left leg, ground reference REF on the right leg
- Breathing measured by the chest belt strain gauge
- Phonocardiogram sensor put on sternum under the chest belt
- Pulse plethysmography sensor on the left-hand finger without strangling

A person sits, relax, does not talk, and periodically breaths.

Data structure: `fs=500 Hz`

```
1. column … ECG [mV]
2./3. column … PCG
2./3. column … respiratory
4. column … pulse plethysmography
```

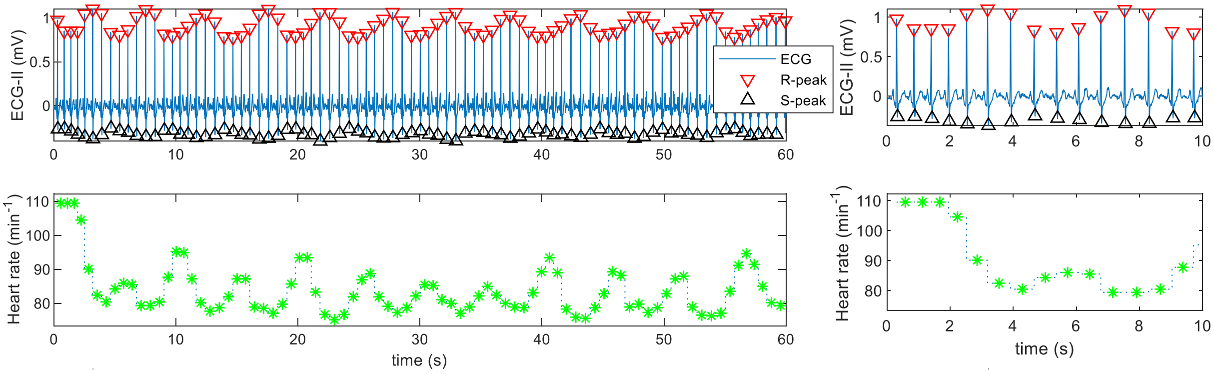


Useful functions: `butter, filtfilt, diff, median, corr, disp, num2str`

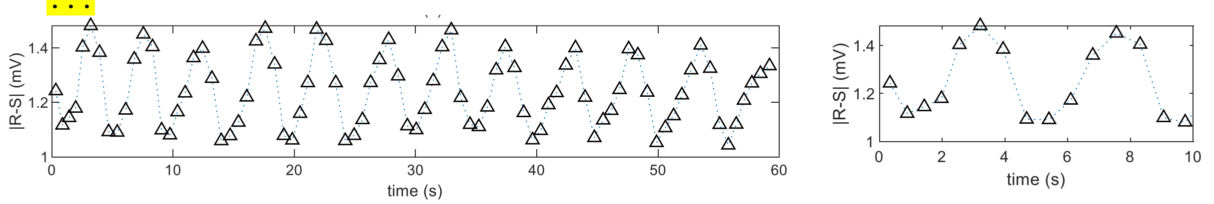
Help:

1. **Respiratory influenced parameters: Extract the parameters from ECG and PPG, that variate with respect to breathing. Correlate the parameters with the chest belt sensor, show the correlation coefficient and p-value. Count the breathing cycles from ECG, PPG and the chest belt sensor.**

```
ecg=data(:,1); % ECG-2nd lead
resp=data(:,2); % respiration
pcg=data(:,3); % phonocardiogram
ppg=data(:,4); % pulse plethysmography

t=linspace(0,(size(data,1)-1)/fs,size(data,1))';

% filter
ecg (0.5-40 Hz)
resp (<0.5 Hz) max. 30 cycles/minute
pcg (unfiltered)
ppg (0.5-8 Hz)
...

% Detect ECG components: R-peaks, S-peaks, ends of T-wave. Use the function
from the previous exercise, solve possible exception. Remember, the number
of R-peaks is higher than S-peaks/T-ends.
[~,~,~,~,~,~,Rm,Sm,~,~,~,Te]=my_ecg_fun(ecg,fs);

a) Measure R-R intervals, recalculate theirs to instantaneous heart rate
   per minute (HR). Note: time indexes of R-R set to half of the interval.
   RR=diff(Rm);
   HR=60*1./(RR/fs); % 60*(1/T) BPM
   HRidx=Rm(1:end-1)+round(RR/2); % t(HRidx) is time of |R-R|/2
```

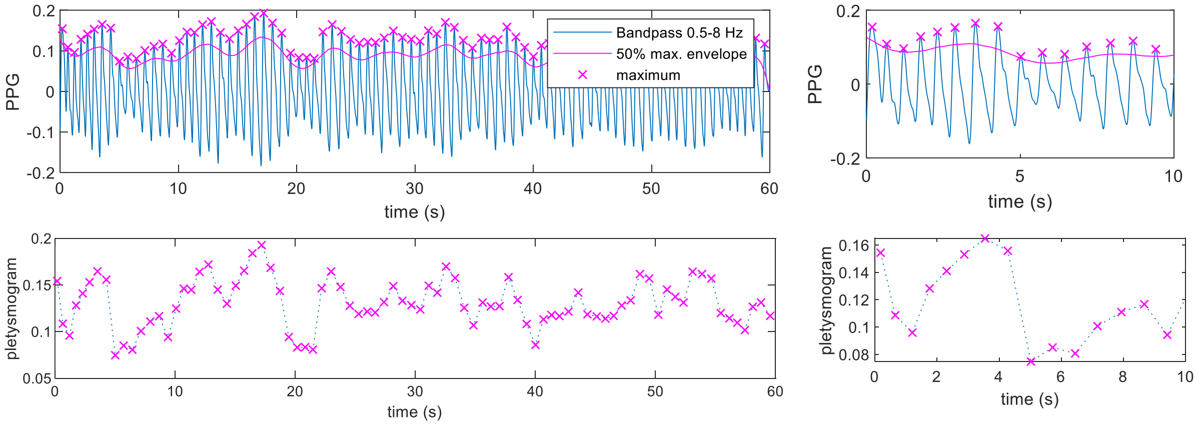



```
b) Measure of amplitudes between R and S peak in ECG |R-S|, show
   variability in time.
   ...
```



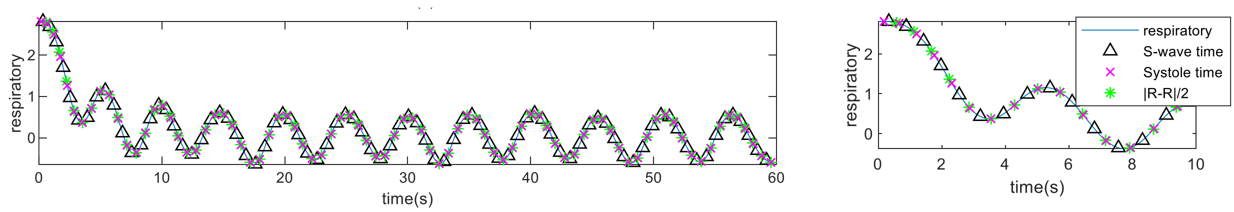
c) Compute PPG signal envelope. Use e.g. MA-filter with 1-3 s window. Detect the systoles in PPG. Use the envelope to the threshold, localize local maxima in PPG. Show systoles variability in time.

```
...
th_max=0.5*max(ppg)*ppg_env/max(ppg_env);

...
```



d) Correlate the parameters with the chest belt signal.

- Instantaneous heart rate × respiration in time of |R-R|/2
- |R-S| amplitudes × respiration in time of S-peak
- Systoles × respiration in time of systoles




```
[C_HR,p_HR]=corr(resp(HRidx),HR)
...
```

```
=== Respiratory correlation to ===
Heart rate:       C=      (p<      )
R-S amplitude:    C=      (p<      )
PPG amplitude:    C=      (p<      )
```

e) Determine the number of breathing cycles per minutes from parameters and the chest sensor.

- inspiration = positive difference, expiration = negative difference
- signum of difference = (+) inspiration, (-) expiration
- number of inspiration = change from (-) to (+)
- number of expiration = change from (+) to (-)
- breath per minute = total number of inspiration/expiration per record duration in minutes

```
=== Respiratory rate ===
chest sensor:      BPM
RR-intervals:      BPM
RS-amplitude:      BPM
PPG-amplitude:      BPM
```

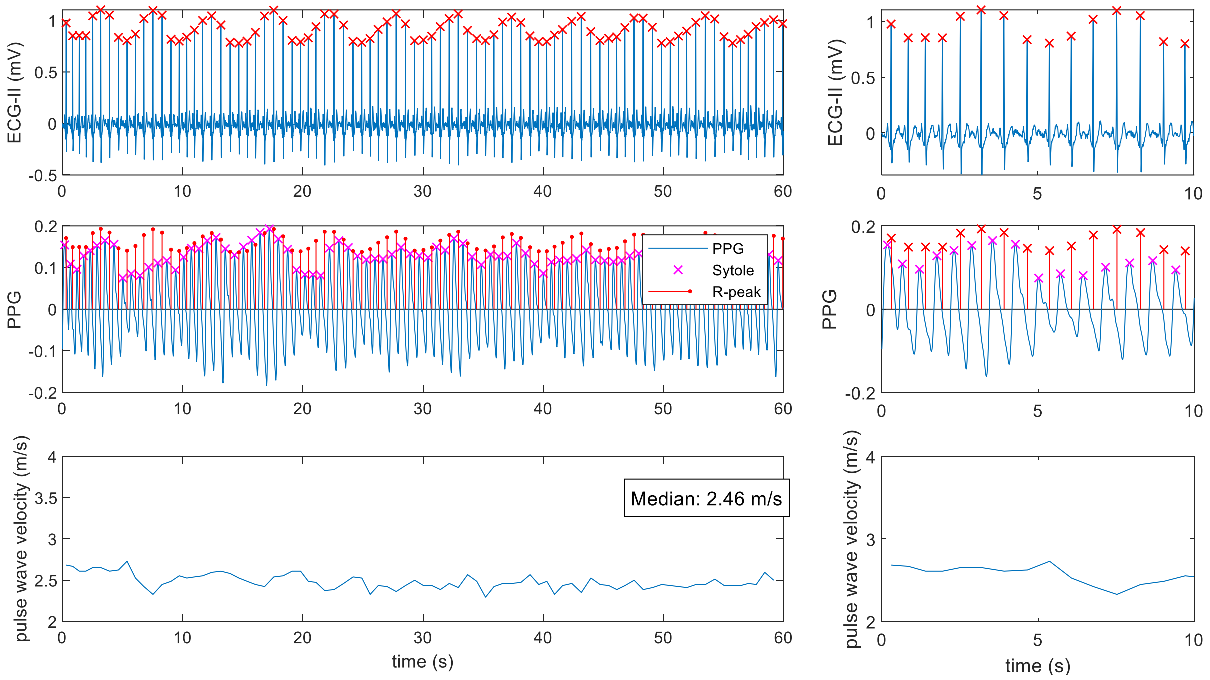
Can we use the ECG to reliable determination of breathing cycles?

What parameter is the best reliable?

2. **Pulse wave velocity: Heart contraction (R-peak) pumps the blood with systolic pressure (maximum v PPG). Fast increase of the pressure is spread by vessels through the whole body as a pulse wave, which arrives at peripheral parts (hands, legs) with time delay. The velocity of the pulse wave (m/s) is defined for the distance from the heart to the PPG sensor. The velocity is increasing in age (lose the bloodstream flexibility).**

a) Measure delay between R-peaks and systoles. Compute the pulse wave velocity in time and median value.

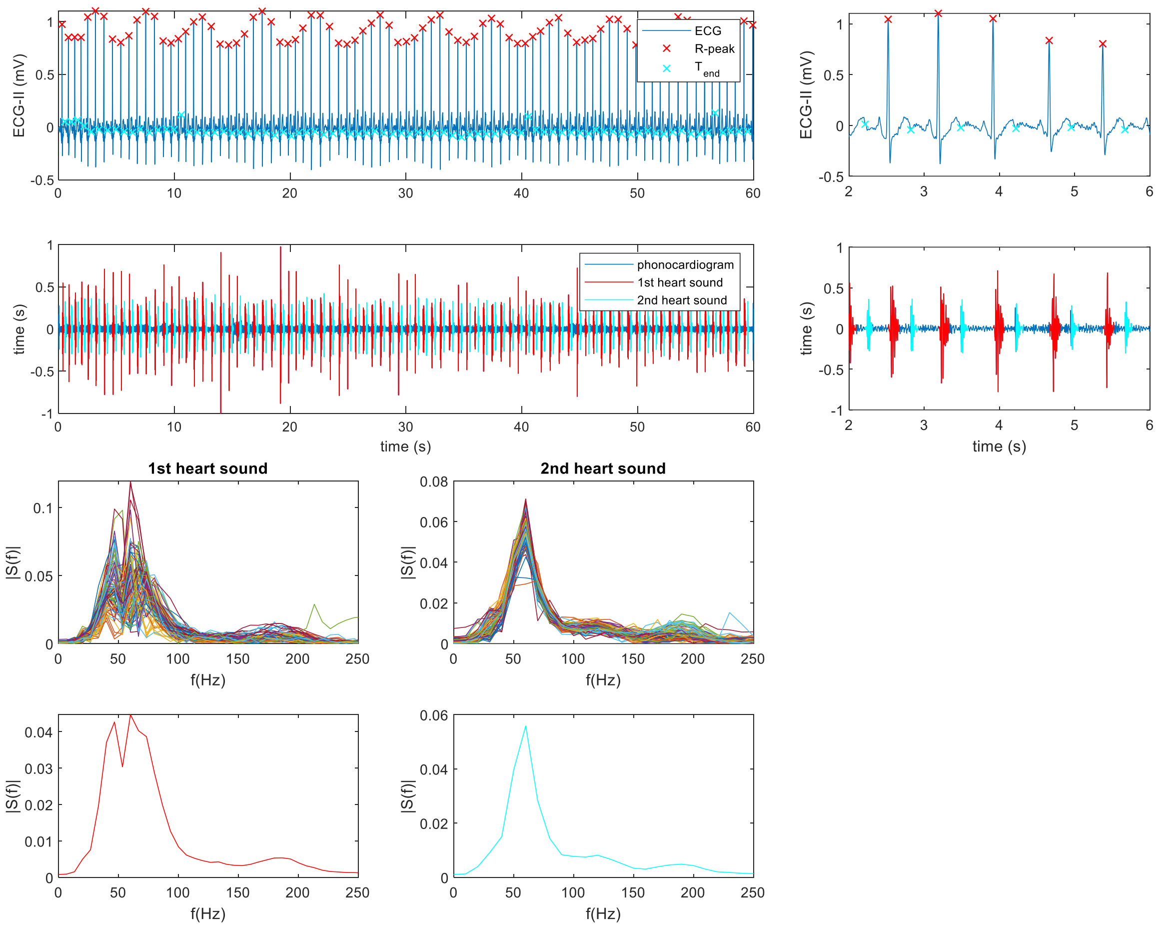
b) Warning! If PPG sensor failures, the systole delay must be calculated from appropriate R-peak. Therefore, add the test of delay smaller than R-R interval.



3. **Segments 1st and 2nd heart sounds. The first sound starts in R-peak and lasts 150 ms. The second sound starts at the end of the T-wave and lasts approximate 100 ms. Use ECG to segment PCG. For each sound compute frequency spectrum. Average spectrums and compute first and second spectral moments.**

```
t1=0.15; % 1st sound 150 ms
t2=0.1; % 2nd sound 100 ms
S1=[];
S2=[];
for i=1:length(Rm)-1
    hs1=pcg(Rm(i):Rm(i)+round(t1*fs));
    hs2=pcg(Te(i):Te(i)+round(t2*fs));

    S1=[S1;(1/length(hs1)*fft(hs1))']; % 1st sound spectrum
    S2=[S2;(1/length(hs2)*fft(hs2))']; % 2nd sound spectrum
end
...
```

$$M_1 = \frac{\sum_{f=0}^{fs/2} f \times |S(f)|}{\sum_{f=0}^{fs/2} |S(f)|} \qquad M_2 = \sqrt{\frac{\sum_{f=0}^{fs/2} f^2 \times |S(f)|}{\sum_{f=0}^{fs/2} |S(f)|} - {M_1}^2}$$



	1st spectral moment (Hz)	2nd spectral moment (Hz)
1st heart sound		
2nd heart sound		