Electrocardiogram – measurement, filtration, leads system

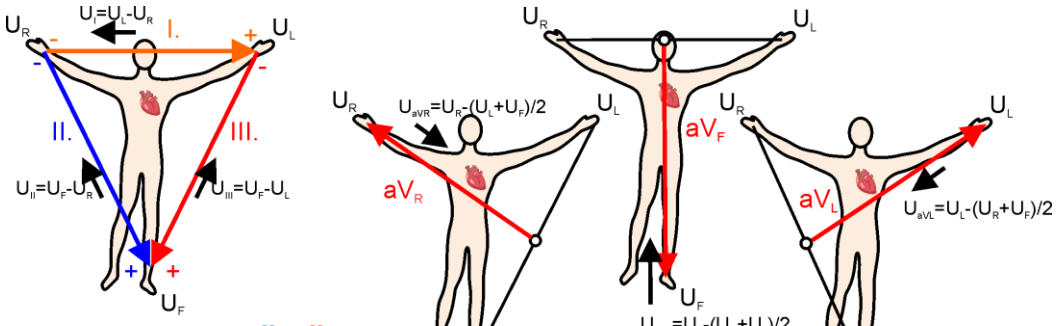
Introduction

Electroencephalography is a simple, non-invasive medical evaluation of a heart. Each heart contraction is accompanied by the weak signal generation, which is spreading to the body surface. The signal can be recorded by the skin electrodes. The time series of the measured signal represents the electrophysiological activity of the heart called electrocardiogram (ECG). A signal voltage is small (<1 mV), therefore the raw signals are often jammed by the noise (mains hum 50/60 Hz, moving artefact – change of half-cell potential <1Hz, EMG >35 Hz). The filtering is necessary for visual inspection and post-processing. Elimination of noise sources improves the quality of signals: electrode placement outside muscles, measurement in lying position, minimising of induction loop of cables, remove power supplies etc.

ECG is a multichannel signal, which is measured between defined potentials (leads). The Einthoven limb bipolar leads (I., II., III.) measure potentials between hands and left leg (U_R, U_L and U_F) in the electrical triangle. The potentials between triangle vertex and opposite basement are called Goldberg leads (aV_R, aV_L, aV_F). The recalculation between Einthoven and Goldberg leads is possible using circuit equations, therefore only I. and II. leads are required. Perpendicular leads (e.g. I, aV_F) allows time-spatial description of potentials spreading in a coronal plane and defines the heart electrical axis in time of R-peaks (health -30 to 105°). Remember, the physiological directions are inverse to electrical and physical direction, e.g. $I.=-U_I$, negative wave = positive voltage.

Basic ECG lead systems:

1. Limb bipolar leads (Einthoven I., II., III. – a combination of potentials between U_R, U_L, U_F)
2. Limb unipolar leads (Goldberg augmented aVL, aVR, aVF – potentials between the limb and averaged remained limbs)
3. Chest unipolar Wilson leads (V_{1-6}) to average limbs reference $(U_R+U_L+U_F)/3$ – unmeasured in exercise.



$$U_L = U_I + U_R$$
$$U_F = U_{II} + U_R$$

$$aV_R = U_R - \frac{U_L + U_F}{2}$$

$$aV_R = U_R - \frac{(U_I + U_R) + (U_{II} + U_R)}{2}$$

$$aV_R = U_R - \frac{2U_R}{2} - \frac{U_I + U_{II}}{2}$$

$$\boldsymbol{aV_R = -\frac{U_I + U_{II}}{2}}$$

Goals:

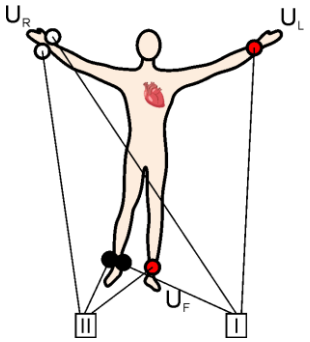
1. Record ECG (I. and II.) contained relaxed 30 s, 15 s in motion, 15 s with inducted hum 50 Hz
2. Filter a low-frequency noise (isoline), mains hum, and high-frequency noise
3. Use the nonlinear filtering to remove isoline (decimation, linear interpolation)
4. Use the filtered leads (I., II.) to generate remained leads (III., aV_R, aV_L, aV_F)

5. Show the heart electrical axis for R-peaks

ECG recording:

I. lead:
- **white (-)**: right hand
- **red (+)**: left hand
- **black (ref)**: right leg

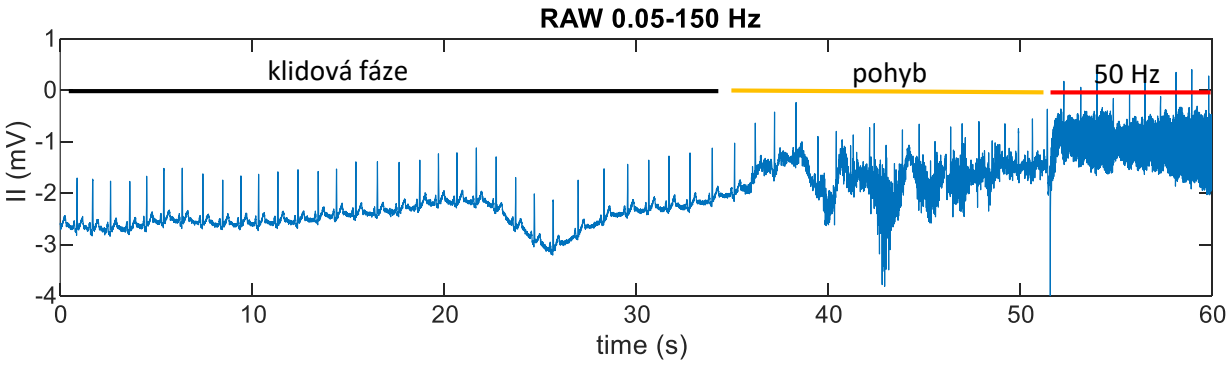
II. lead:
- **whit (-)**: right hand
- **red (+)**: left leg
- **black (ref)**: right leg



First 30 s is sitting measurement. The measured person cannot speak, will be relaxed, and normally breath to eliminate myopotentials. The person will start moving in next 15 s (can stand up, make few knee-band). The last 15 s is in sitting position; an assistant makes the induction loop around some notebook power supply or touches the active part of the recording electrode for contaminating signals by main hum noise.

Data structure: fs=500 Hz

1. column … lead I [mV]
2. column … lead II [mV]



Useful function:

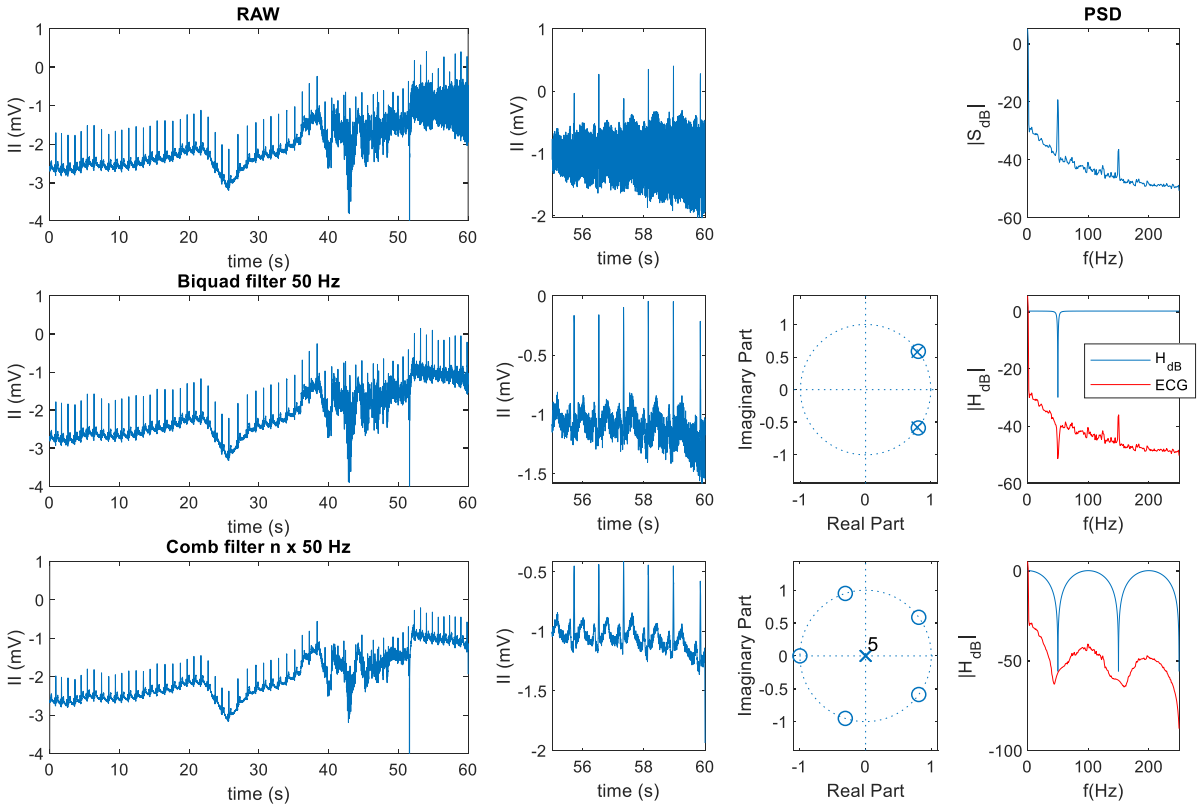
butter, freqz, zplane, impulse, filtfilt, pwelch, resample, findpeaks, compass

Help:

A. Main hum filtering (50 Hz). Use the II. lead.

```
data=load('ECG_test_500Hz_v3.txt');
fs=500; % Hz

II=data(:,2);
t=linspace(0,(size(II,1)-1)/fs,size(II,1));

1) Plot ECG signal, show a detail of 50 HZ noise section. Use function
   (pwelch) to estimate the power spectral density PSD
[psd,f]=pwelch(II,fs,fs/2,[],fs); % PSD
psd_dB=10*log10(abs(psd)); % PSD v dB

2) Design IIR biquad (notch) filter to remove 50 Hz. Plot the filtered
   signal, position of poles and zeros, and transfer function
R = 1; r = 0.98;
f0=50;%Hz
b = [1 -2*R*cos(2*pi*f0/fs) R*R];
a = [1 -2*r*cos(2*pi*f0/fs) r*r];
f1_II=filtfilt(b,a,II);
... add another notch-filter to remove higher harmonic component of 50 Hz

3) Design FIR comb filter to remove 50 Hz and another higher harmonic
   component. Plot the filtered signal, position of poles and zeros, and
   transfer function
b = 0.5*[1 0 0 0 0 1]; % for fs = 500 Hz
a = 1;
```

How looks the coefficient of comb-filter for different fs?
What is the advantages and disadvantages of comb-filter vs. notch-filter?



B. Filtration of low and high-frequency noise. Use the II. lead.

1) Show ECG signal and detail of moving artefact section.
2) Design a high-pass filter to remove isoline (>1 Hz). Find the maximal stabile filter order. Show its parameters similarly as in previous section

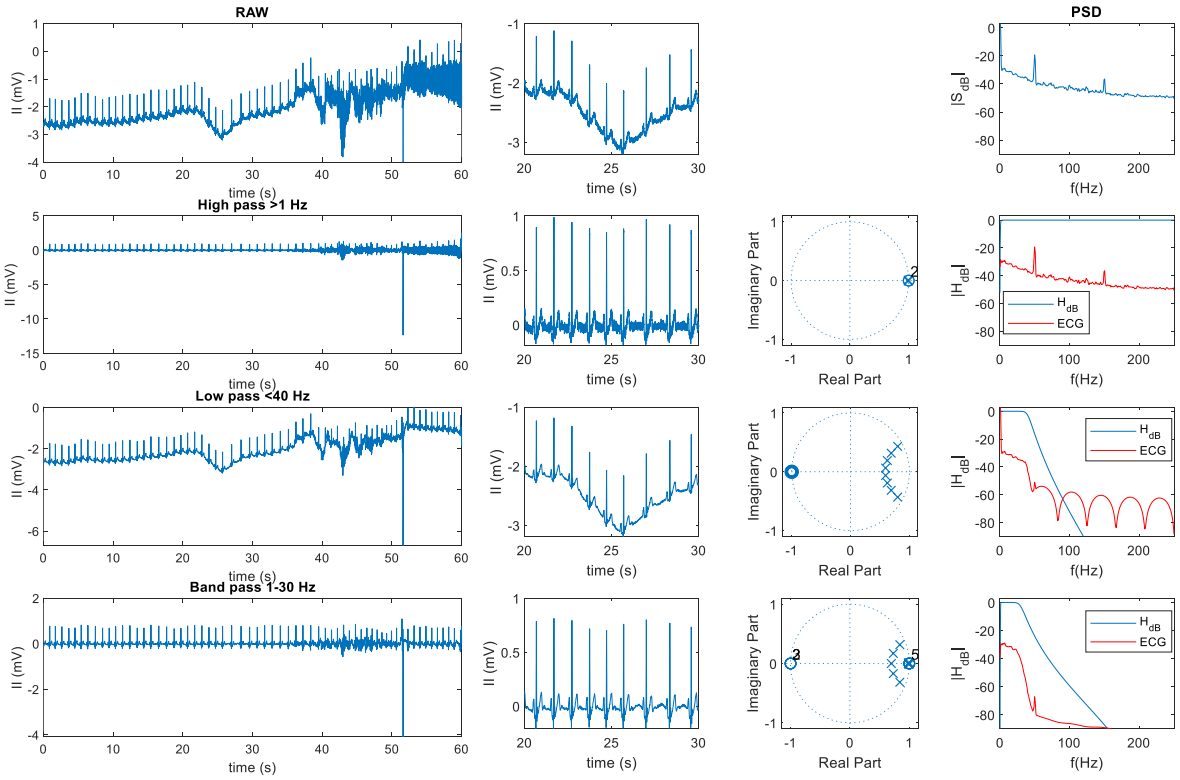
```
f0= 1; % >1Hz
[b,a] = butter(2,2*f0/fs,'high');
```

3) Design low-pass filter to remove high-frequency noise (<40 Hz). Did the filtering distort the ECG? Can you remove EMG activity?

```
f0= 40; %Hz <40 Hz
[b,a] = butter(8,2*f0/fs,'low');
```

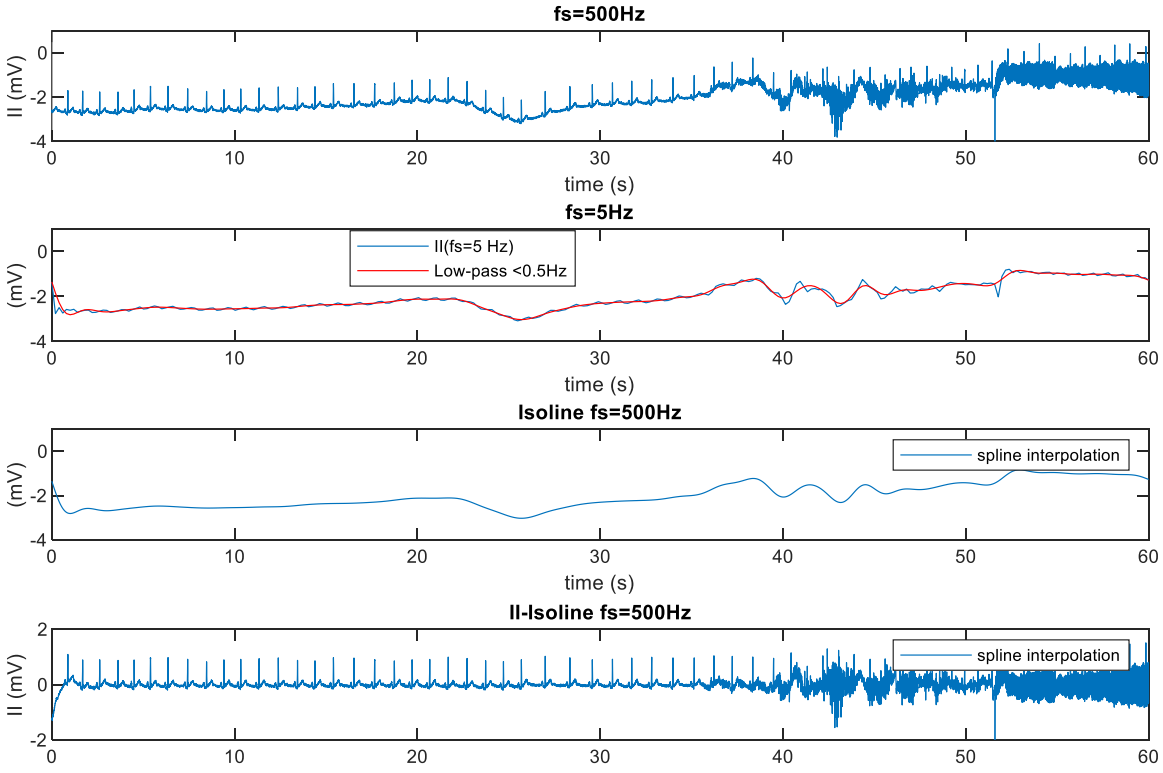
4) Design band-pass filter to common removing of isoline and high frequency noise (1-30 Hz). How did it distort the ECG?

```
f0= [1 30]; %Hz 1-30 HZ
[b,a] = butter(5,2*f0/fs,'bandpass');
```



C. Removing very slow spectral components in signals with the high sampling frequency. Using of sharp filters close to DC (e.g. <0,5 Hz), that is caused by the half-cell potential changes between electrodes and skin, sweating, slow movement, is practically impossible due to inability to design stable filter. The faster sampling complicates the design process to achieve the required filter. The possible process is the extraction of the low-frequency signal component, which is subtracted from the original signal.

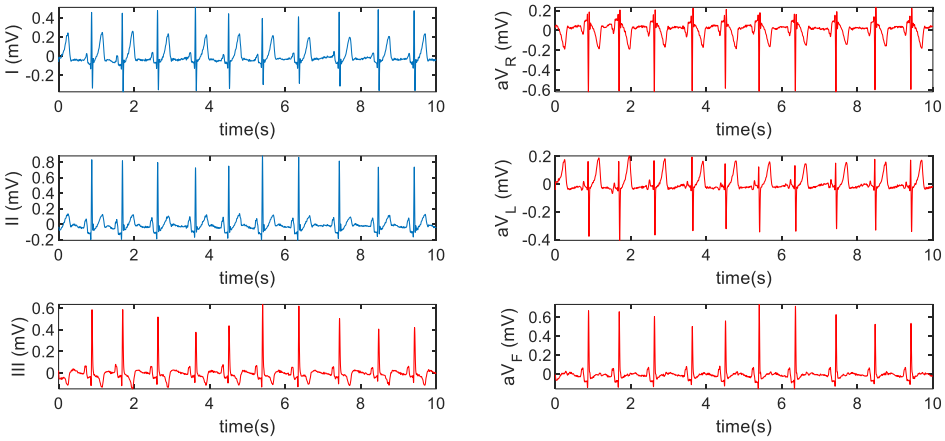
```
1) Decimate the signal to lower sampling frequency with a low ratio of filter
   frequency fs/f0. The decimation ratio fs/fs_new should not cross 10, where
   start a similar effect with anti-aliasing (low-pass) filter design. Use
   decimation gradually for the initial high ratio.

f0=0.5; % frequency of low-pass
fs_new=5; % frequency of final decimated signal

r=fs/fs_new; % r=100 !!!
IIdec=resample(II,50,fs); % fs: 500->50Hz r=10;
IIdec=resample(IIdec,fs_new,50); %fs: 50->5 Hz r=10;


2) Filter decimated signal by low-pass filter with required f0
[b,a]=butter(5,2*f0/fs_new,'low');
isoline=filtfilt(b,a,IIdec);

3) Interpolate the low sampled isoline (fs=5 Hz) to original fs=500 Hz
tdec=linspace(0,size(isoline,1)/fs_new,size(isoline,1));
isoline=interp1(tdec,isoline,t, 'spline');
isoline=isoline(:); % to column as II

4) Subtract isoline from original signal
II=II-isoline;
```



D. Finally, filter I. and II. leads of ECG in the relaxed section (0-30 s), generate the remained leads (III., aVR, aVL, aVF). Show heart electrical axis in time and average vector for R-peaks.

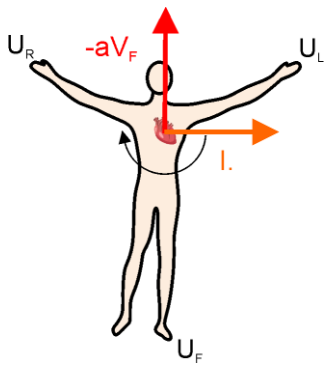
```
1) Filter ECG by the appropriate band-pass
relaxed=data(1:30*fs,:); % I a II leads
[b,a]=...
relaxed=filtfilt(b,a,relaxed);
```

```
I=relaxed(:,1);
II=relaxed(:,2);
III=II-I;
aVr=-(I+II)/2;
aVl=(I-III)/2;
aVf=(II+III)/2;
```




```
2) Detect R-peaks in II lead, compute heart electrical axis. Use 50% of ECG
   maximum threshold to R-peaks detection.
```

```
th=0.5*(max(II)-min(II)); % threshold
[~,idx]=findpeaks(II,'MinPeakHeight',min(II)+th);

avrI=mean(I(idx));
avraVf=mean(aVf(idx));

plot(I,-aVf); axis image; % vector ECG in time
hold on
compass(avrI,-avraVf,'r'); % R-axis
```



... Use the goniometric function to compute the angle of the R-axis.