I. Filtering and baseline correction of a physiological signal

During the acquisition process, physiological signals are affected by multiple sources of noise. The pre-processing stage is very important in order to minimise the effect of these disruptive interference as much as possible, while taking great care to retain the useful components of the signal. Among the most common types of interference are those caused by the electrical grid (the '50 Hz'), fluctuations in the base line (due to breathing or the patient's movements).

One of the first operations is therefore to set up a filter that eliminates these disturbances.

I.1 Representation of a digital filter in MATLAB

A digital filter is generally represented by its transfer function in z. In MATLAB, a z transfer function is characterised by two vectors containing the coefficients of the powers of the numerator and denominator of the transfer function in question under consideration.

Ex: The following transfer function in z :

$$H(z) = \frac{1}{2} + \frac{1}{2}z^{-1} = \frac{0.5 + 0.5z^{-1}}{1 + 0z^{-1}}$$

will be represented in Matlab by :

```
»num=[0.5 0.5];
»den=[1 0];
```

I.2 Temporal and frequency response

A filter can be analysed on the basis of its temporal and frequency responses. The various modes of representation are complementary and translate the characteristics of a filter in different ways.

I.2.1 Impulse response

The impulse response is plotted directly using the *impz*:

```
»impz(num,den)
```

I.2.2 Frequency response

There are two main categories of digital filters: finite impulse response (FIR) filters and infinite impulse response (IIR) filters.

FIR filters are characterised by the transfer function :

$$H(z) = B(z) = b_0 + b_1 z^{-1} + \cdots b_n z^{-n}$$

Whereas IIR filters are characterised by the transfer function :

$$H(z) = \frac{B(z)}{A(z)} = \frac{b_0 + b_1 z^{-1} + \cdots + b_n z^{-n}}{a_1 z^{-1} + a_2 z^{-2} + \cdots + a_n z^{-n}}$$

Where n is the filter order.

I.2.2.1 Infinite impulse response filters

In the lines below, we want to plot the response of the IIR 5th-order butterworth digital bandpass filter with cut-off frequency [20 80].

```
%5th-order butterworth bandpass filter – IIR filter-
order=5 ;
fs=1000;
w=[0.04 0.16]; % la bandpass w=[20-80] Hz
[b,a]  =  butter(order,w,'bandpass')%  calculation  of  Butterworth  filter
coefficients
[h,w]=freqz(b,a,fs)% filter frequency response réponse
ah=abs(h)% calculation of the filter response amplitude
ag=angle(h)% phase calculation of filter response
figure(2)
subplot(211),plot(w,ah,'k');grid on;title('Amplitude filter ');
subplot(212),plot(w,ag,'k');grid on;title(' Phase filter');
```

Note

The IIR Chebyshev Type 1 or 2 digital filter can also be used, using the cheby1 or cheby2 instruction respectively.

I.2.2.2 Finite impulse response filters

```
% a low-pass RIF filter with cut-off frequency fc=30Hz
order=5 ;
fs=1000;
w= 0.16; % the cut-off frequency w=80 Hz
[b,a] = fir1(ordre,w,'low')%calculation of butterworth filter coefficients
```

I.3 Filtering a signal in MATLAB

```
fs=1000;
N=1024;
t=(1:N)/fs;
```

```
n1=5;
w=400/500;
[b,a] = butter(n1,w,'high');
data=sin(2*pi*100*t)+sin(2*pi*400*t) ;
figure(1)
plot(data)
sf=filter(b,a,data);
figure(2)
plot(sf)
ps1=abs(fft(data));
ps2=abs(fft(sf));
figure(2)
plot(ps1(1:length(ps1)/2-1)),hold on, plot(ps2(1:length(ps1)/2-1),'r')
```

Work

Generally speaking, the QRS complex has its maximum energy in the 2.5-30 Hz bandwidth. It is therefore preferable to filter this signal as a first step and before any analysis. The filter used is a Butterworth recursive digital filter with a bandwidth of 2.5-30 Hz, and order 5. We will therefore use 4 ECG signals, one representing a normal case and three representing pathological cases. The recordings were sampled at 360Hz.

```
clear all
close all
load('100sf1.mat') % charger le signal
x=s1(1:1000);
figure(1)
plot(x);grid on;title(' A raw ecg signal')

%5th-order butterworth bandpass filter
order=5 ;
fs=360;
w=……; % bandpass w=[2.5-30] Hz
[b,a]   =   ……..%   calculation   of   butterworth   filter   coefficients
[h,w]=……..% filter construction
ah=……..%   calculation   of   the   filter   response   amplitude
ag=……..%   calculation of the filter response phase
figure(2)
subplot(211),plot(w,ah,'k');grid on;title(''Amplitude filter');
subplot(212),plot(w,ag,'k');grid on;title(' 'Phase filter ');

%signal filtering
x1=……..% filter the noisy signal
figure(3)
plot(x1);grid on;title('filtered ecg signal')
```

1. Use the R-peak detection approach using a fixed threshold for recordings 108, 109 and 232.
2. Explain the results obtained.