1 Introduction

The objective of this report is to present different basic signal processing techniques and the study their application to real-life signals. The first exercise consists in the analysis of the effects of different implementation of low-pass filters in order to remove a 50 Hz perturbation of and ECG signal. The objective is to discuss how the signal and the PQRST complexes are affected by the filtering. The second exercise in an application of the Hilbert transform that can be used for the estimation of the instantaneous envelope and frequency of a signal. The exercise focuses on a breathing measurement signal. The last exercise consists in using filtering techniques in order to detect an hand-washing event in a wrist-located measurement of the acceleration.

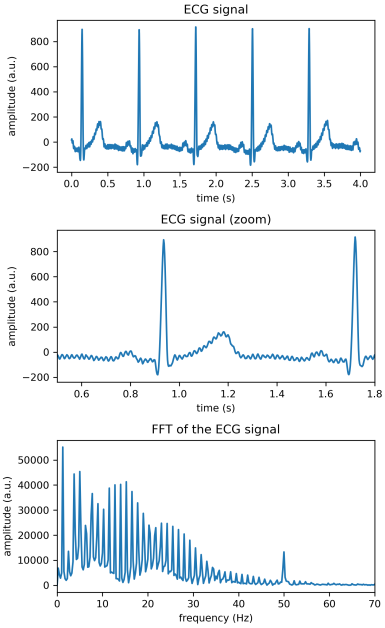

Figure 1: Time and frequency plots of the ECG signal.

2 Ex. 01, ECG enhance

The objective of this exercise is to study different types of filters and their effects on the signals. The illustrative example is an example of an ECG signal depicted in figure 1. In the middle sub-figure the 50 Hz perturbation is clearly visible on the temporal plot of the signal. The spectral analysis of the signal using a Discrete Fourier Transform (DFT) clearly shows the 50 Hz oscillations. These oscillations will degrade the detection of the onset of the different waves (*e.g.* p-waves). It is therefore suitable to remove this perturbation. It can also be observed that the spectrum of the ECG signal spreads over a frequency range larger than 50 Hz. By the use of a low pass filter with a cut-off frequency below 50 Hz will imply an attenuation of the highest frequencies of the ECG thus the sharp peaks will have a reduced amplitude and some oscillation can take place due to the truncation of the ECG spectrum..

The first filter is an Infinite Impulse Response filter (IIR) with a pass-band up to 35 Hz and a stop-band above 50 Hz with a minimum attenuation of 40 dB. The plots of the signal before and after filtering are presented in figure 2. The analysis of the filtered waveform shows that the 50 Hz perturbation is significantly attenuated and the detection of the PQRST complexes is improved. The filtered waveform also exhibits a delay compared to the input signal. The sharp transition between the pass-band and the stop-band and the non-linear phase of the filter produces an oscillation after the r-wave that masks the s-wave. As the R peak is similar to an impulse signal, the observed oscillation are the impulse response of the filter. The p-wave and the end of the t-wave are clean of the 50 Hz perturbation. As expected, the amplitude of the q-wave and r-wave are reduced to the to removal of the components above 35 Hz.

The application of the same filter using a zero-phase approach permits to compensate the effects of the non-linear phase of the filter (figure 3). The PQRST complexes are now clearly visible. Oscillations around the QRS can be observed. The oscillation are due to the high frequency components (above 35 Hz) that have been discarded. It can be observed that these oscillations are not due to the 50 Hz perturbation (slightly different frequency) but are caused by the filter structure and the truncation of some part of the ECG signal frequency content.

The application of linear-phase filter (figure 4) permits to obtain a removal of the 50Hz component. The filtered signal exhibits a constant delay compared to the original signal. The delay is equal to the half of the length of the linear-phase filter. It can be observed that some of the 50 Hz residues can be observed after the t-wave. This is due to the transition between pass-band and stop-band that is less sharp than those of the IIR filter and is results in a smaller attenuation at 50 Hz. In order to increase the attenuation the length of the filter would need to be increased.

In conclusion linear-phase and zero-phase filters are suitable for the analysis of the PQRST complexes. The IIR filter introduces toio much distortion in some of the complexes to be suitable. The linear phase filter would be preferable for real-time implementation because it is causal (depends only on present and past samples). A better solution would be to use a narrow stop-band filter around 50 Hz what would allow to preserved the higher frequencies in the ECG signal.

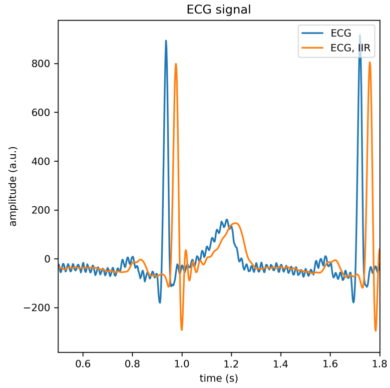

Figure 2: ECG signal after IIR filtering.

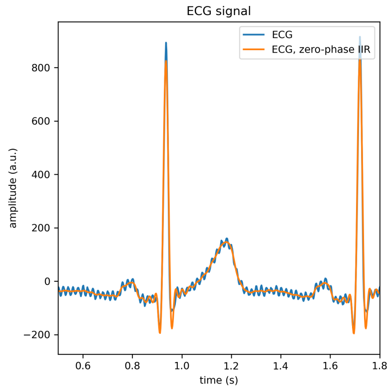

Figure 3: ECG signal after zero-phase filtering.

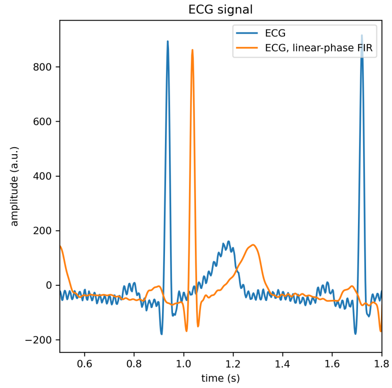

Figure 4: ECG signal after linear phase filtering.

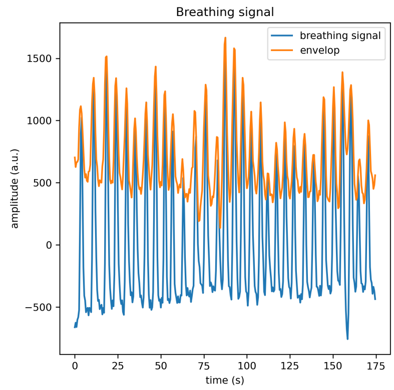

Figure 5: Original breathing signal and Hilbert amplitude envelope.

3 Ex- 02, breathing estimation

The objective of this exercise is to use the Hilbert transform to estimate the instantaneous amplitude and frequency of a signal. The Hilbert transform of a signal consists in computing the DFT of a signal and setting all the components of the negative frequencies to zero before computing the inverse DFT. The resulting signal is complex and its argument corresponds to the instantaneous amplitude and the derivative of its phase of the signal to the instantaneous frequency of the signal. The interpretation of the Hilbert transform has a direct meaning when the signal is narrow-band. Figure 5 presents a respiration signal (impedance measurement of the chest volume) and the argument of the Hilbert transform of the signal. One can observe that the argument of the Hilbert transform does not correspond to the amplitude envelope of the signal because the signal is not narrow-band. When the signal is not narrow band the amplitude of the Hilbert transform corresponds roughly to the upper amplitude envelope of the absolute value of the signal.

In order to be able to use the Hilbert transform to estimate the amplitude envelope and the frequency of breathing the respiration signal is band-pass filter between 0.1 and 0.25 that corresponds to normal breathing rate at rest. Figure 6 shows the filtered signal and the Hilbert amplitude envelope. The estimated envelope corresponds to the breathing amplitude. In this case the narrowing the frequency band permits a correct estimation of the amplitude.

In order to estimate the instantaneous frequency of a signal using the Hilbert transform the phase is first calculated. By convention the phase is between $-\pi$ and π as presented in the upper plot in figure 7. In order to obtain a continuous phase, the signal is unwrapped. This unwrapping procedure consists in adding 2π for each jump of the phase signal. The results is presented in the lower plot of figure 7. The unwrap function can be viewed as the inverse of the modulo function.

The derivative can be approximated by computing the difference between 2 consecutive samples of the phase signal ($\frac{d\phi}{dn} = \phi(n) - \phi(n-1)$). The obtained signal is the digi-

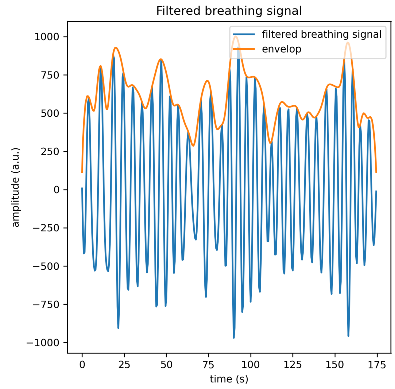

Figure 6: Band-pass filtered signal and Hilbert amplitude envelope.

tal angular frequency. In order to convert it in a meaningful value this estimation is divided by 2π to obtain digital frequency and multiplied by the sampling frequency and by 60 to obtain a results in breathing per minute. Figure 8 presents the original signal and the instantaneous breathing frequency using the Hilbert transform. The observation of the two signals shows that the instantaneous estimation of the breathing frequency corresponds to the cycle-by-cycle variations of the breathing signal.

In conclusion the Hilbert transform is a useful tool to estimate the instantaneous amplitude and frequency of signal but it undergoes to the limitation that the input signal has to be narrow-band.

4 Ex. 03, hand washing detection

The objective of this exercise is to use filtering techniques in order to select the spectral region of interest for a simple event detection example. The event to be detected in the hand-washing sequence using a wrist-located acceleration measurement. Figure 9 presents the acceleration signal for different (unknown) activities with the hand-washing event that takes place between 20 and 30 seconds. The analysis of the signal shows that, outside the hand-washing event) most of the signal consists in low frequency variations (orientation of the wrist in the gravity field) and short duration movements. During the hand-washing the signal exhibits a periodicity in the movements.

In order to analyse the signal during the hand washing the acceleration signal is high-pass filtered with a cut-off frequency of 0.5 Hz. Figure 10 presents the signal after high-pass filtering (upper plot) and a detail during hand-washing (lower plot). The rough estimation of the period of the oscillations during the hand washing show that it corresponds to oscillations between 2.4 and 3.2 Hz.

In order to enhance the frequency band of the hand-

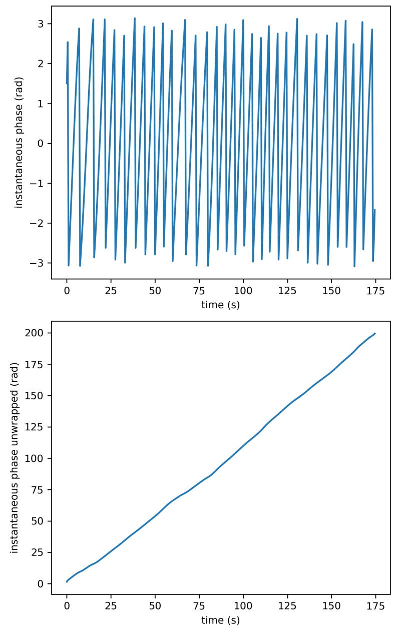

Figure 7: Phase and unwrapped phase of the band-pass filtered respiration signal.

washing and to discard the frequencies outside this range a band-pass filter is applied. Figure 11 shows the signal band-pass filtered between 2.4 and 3.6 Hz. One can observe that the amplitude of the signal is larger, as expected, during the hand-washing.

In order to permit a detection the squared value of the signal is low-pass filtered with a cut-off frequency of 0.4 Hz. The use of the squared value permits to increase the amplitude difference between the event and the rest of the signal. The low-pass filter remove the oscillation and results in a smooth signal suitable for the detection. The obtained signal is presented in the upper plot of figure 12. From this figure one can see that applying a threshold on the low-pass filtered squared signal permits to differentiate between hand-washing and the other events that take place during the signal recording. The lower plot shows the detection using a threshold fixed at 2000.

In conclusion the use a *ad-hoc* filtering permits to make a very basic detection algorithm for the detection of hand washing events.

5 Conclusion

During these laboratory exercise we have used different signal processing methods to perform different operation on real-life signals. The correct understanding of the theory behind these techniques permits to select the correct approach among a plurality of possible solutions.

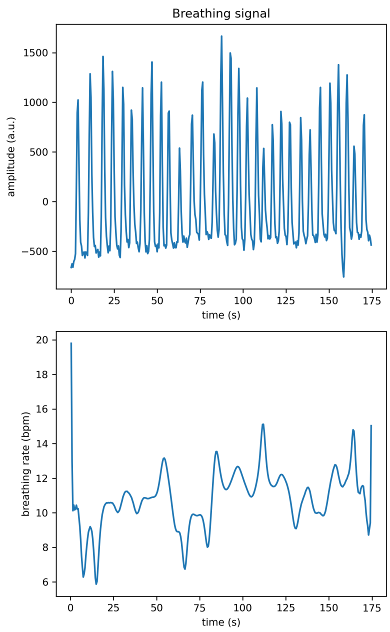

Figure 8: Estimation of the instantaneous breathing rate using the derivative of the phase of the Hilbert transform.

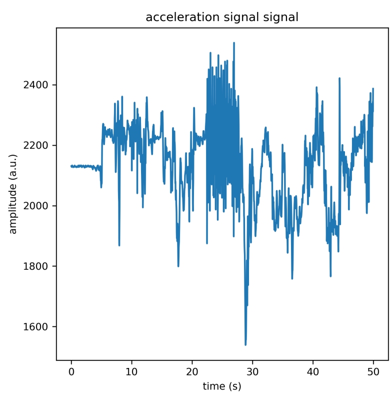

Figure 9: Time and frequency plots of the ECG signal.

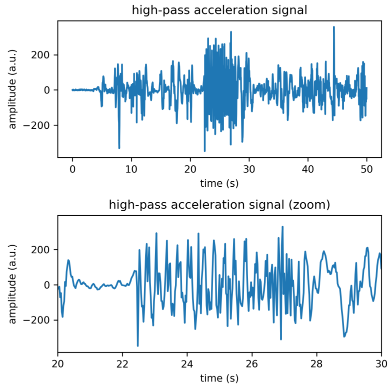

Figure 10: Time and frequency plots of the ECG signal.

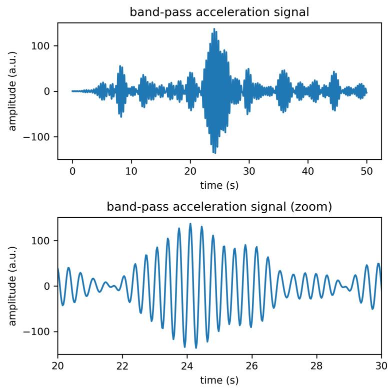

Figure 11: Time and frequency plots of the ECG signal.

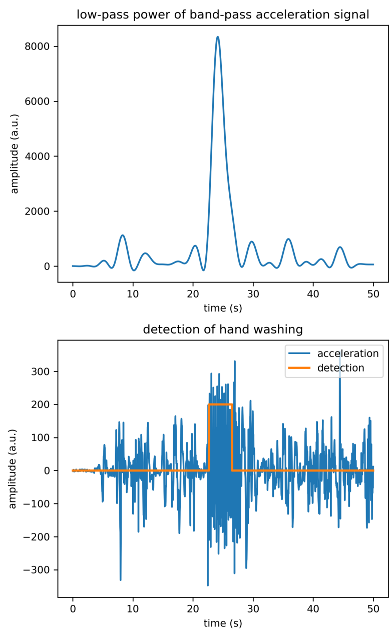

Figure 12: Time and frequency plots of the ECG signal.