EE512 – Applied Biomedical Signal Processing

Practical session – Instantaneous Frequency

Instructions

- Please submit your report as a single PDF file.
- We recommend working in a group of 3–4 students; you can prepare one single report for the group (`name1_name2_name3_lab_InstantaneousFrequency.pdf`), but every member needs to upload the same file individually.
- There are 3 experiments consisting of questions testing your understanding and correct interpretation of the signals and the results.
- The Matlab functions for each experiment are already provided. Inlude in the report ONLY the code/lines used to call the Matlab functions and to visualize the signals/results, BUT not the code of the provided functions.

Useful in-house Matlab functions

AR_psd	power spectral density, parametric estimation
IFhilbert	IF estimation using Hilbert transform
Teager	IF estimation using Teager-Kaiser
STFT	IF estimation using STFT
AdaptBP	IF estimation using adaptive bandpass filter
AdaptBP_weight	IF estimation using adaptive bandpass filter on multiple signals

Additional build-in Matlab commands

buttord	determination of filter order
butter	IIR filter synthesis
filtfilt	output of a filter with forward and backward filtering
freqz	filter frequency response
resample	signal resampling

Experiment 1: the importance of pre-filtering for instantaneous frequency estimation

The file "**AA_AFib**" contains 500 samples from the 12 surface ECG electrodes (sampling frequency Fs = 50 Hz) during an episode of atrial fibrillation, after ventricular activity cancellation.

1.1 Bandpass filter (frequency range from 4 to 7 Hz) the signals from the electrodes V3 and V4 (columns 9 and 10) using an IIR filter synthetized with:

```
>> [Nb,wn] = buttord([0.16 0.28], [0.12 0.32],0.5,20);
>> [b,a] = butter(Nb,wn);
>> signal_filt = filtfilt(b,a,signal);
```

Due to physiological constraints, the atrial fibrillation frequency lies into the interval [3-12]Hz, but the frequency range usually met in clinical practice is [4-7]Hz.
Q1.1. Is the frequency response of the filter adequate?

Note. To visualize the amplitude response, the simplest way is to use:

```
>> [h,w]=freqz(b,a,1000);
>> plot(Fs.*linspace(0,0.5,1000),abs(h))
```

Visualize the signals and the corresponding power spectral densities (parametric spectral estimation using an order of 20) before and after bandpass filtering.

```
>> [Px, freq] = AR_psd(signal, 20, 50, 25, 0, 1);
```

Q1.2. The maximum frequency for the plot is set at 25Hz. Why wouldn't it make sense to visualize a spectrum of higher frequencies?

1.2 Use the Matlab function IFhilbert, teager, STFT(Hamming window of length M = 31) and AdaptBP (f0 = 5, beta = 0.85 or 0.98, delta = 0.9) to estimate the IF, first on the two raw signals of the previous experiment, then on the outputs of the bandpass filter.
Q1.3. Conclusion? Which method is the most effective? Was the bandpass pre-filtering worth it? How does the beta coefficient affect the IF estimation? Why?

Experiment 2: indirect estimation of respiration frequency from respiration sinus arrhythmia (RSA) during a VO2-max test

RSA is the modulation of RR intervals induced by respiration. VO2 max is the maximum rate of oxygen consumption during an incremental effort. It is an important indicator of physical fitness, especially with regard to endurance capacity. Other variables of interest are the ventilatory thresholds that correspond to the exercise intensity at two specific instants of the effort. These instants correspond to significant changes in the time evolution of the respiration frequency (RF). The latter can be monitored using a mask, but this is uncomfortable for the subject. Indirect estimation of RF using RSA is clearly a promising solution.
In this experiment, we are using a recording of the RR-intervals during a VO2 max test (3 minutes of rest, 3 minutes cycling at 85 rpm without a load, then load increasing by 1 W every 2 seconds). A mask was used to obtain the reference RF. The idea is to develop an RSA-based scheme for RF estimation from the RR-intervals.

The file "**VO2max**" contains several variables:

t	sampling times of the regularly resampled RR intervals
RR	RR-intervals sampled at 4 Hz
tr	sampling times of the respiration frequency (mask)
RF	respiration frequency

2.1. Plot the RR and RF signals.
2.1 Design an high-pass IIR filter to remove the low-frequency components in the RR signal and keep only the components with frequency > 0.15 Hz.

```
>> [Nb,Wn] = buttord(0.4/4,0.2/4,0.5,20) ;
>> [b,a] = butter(Nb,Wn, 'high') ;
>> Resp = filtfilt(b,a,RR-RR(1));
```

Q2.1. Check that the output signal represent the respiration component only.

2.2 Use the Matlab function IFhilbert, Teager, STFT (window length M = 31), and AdaptBP (f0 = 0.25, beta = delta = 0.925) on the resulting fitered signal. You needs to lowpass filter the IF estimates using for instance:

```
>> IFf = filtfilt(a,[1 a-1],IF);
```

for a suitable value of a (e.g. a = 0.05).

Q2.2. Assess the performances by visually comparing the IF estimate wiht the reference respiration frequency.

Experiment 3: extraction of a common oscillation and estimation of its instantaneous frequency using bandpass adaptive filtering

The file "heart_3" contains (columns, sampling frequency 4 Hz) the RR-intervals, blood pressure, and respiration of one subject breathing spontaneously.
Two phenomena are of particular interest in signals of this type. First, respiration modulates the RR-intervals (the so-called sinus arrhythmia) and, to a lesser estend the blood preasure. Second, the baroreflex, i.e. the dynamic regulation of blood preassure by heart rate variability, mediated by the autonomous nerve system, leads in rest conditions to a modulation at a frequency between 0.05 and 0.1Hz of the RR-intervals.

3.1. Remove the mean values and resample the signals at 1 Hz. Visualize the signals and the corresponding power spectral densities (parametric spectral estimation using an order of 20) before and after downsampling.

```
>> [Px, freq] = AR_psd(signal, 30, 1, 0.5, 0, 1);
```

Q3.1. Why were the signals downsampled from 4Hz to 1Hz?

3.2 Use AdaptBP_weight to extract the common oscillation between the RR-intervals and the respiration (f0 = 0.2, beta = 0.9, delta = mu = 0.95).
Q3.2. What do the two filter outputs represent? Check visually that the amplitude of the two filter outputs are well correlated. What does the estimated IF represent? Compare the variation of the IF estimate with a non-parametric spectrum estimate of the respiration signal.

3.3 Use AdaptBP_weight to extract the common oscillation between the RR intervals and the pressure (f0 = 0.06, beta = 0.9, delta = mu = 0.95).
Q3.3. What do the two filter outputs represent? Are the amplitudes of the two filter outputs correlated?