# — Fetal ECG extraction —

The aim of this lab tutorial is to extract the fetal ECG during delivery from abdominal sensors. Two database will be used:

- The first one has been recorded at TIMC laboratory on a healthy adult in the context of a research collaboration.
- The second one was acquired in the Department of Obstetrics at the Medical University of Silesia [1] and can be downloaded from the Physionet website [2].

The lab session is divided in two parts as detailed below.



Some useful Matlab functions are provided. The first thing to do is to refer to the help: `help FunctionName` which describes the aim of the function, the inputs parameters and the outputs variables.

# 1 Healthy ECG signal analysis

## 1.1 Basic analysis

**Manipulation**

Edit the script `main_BasicAnalysis.m` to

- Load the matlab file `HealthyECG.mat` (`Fs` is the sampling frequency and `x` is the ECG data).
- Plot the spectrum of the ECG and **comment** it.
- Plot the spectrogram of the ECG, **comment** your choice of the parameters values on the result.

## 1.2 R peak detection

The sampling frequency in the remainder of this lab session is 1kHz. **You thus need to adapt all the parameters accordingly.**

The derivative filter in [3] will be replaced by

$$H(z) = z^{-2}\,\frac{z^{-2} - 8z^{-1} + 8z^{1} - z^{2}}{12}, \tag{1}$$

to approximate the derivative by the five-point stencil method.

ERRATUM: there is an error in the article [3]. Please note that the high pass filter described on page 232 (in the Methods section) has a transfer function defined by

$$H(z) = \frac{-1 + 32z^{-16} - 32z^{-17} + z^{-32}}{1 - z^{-1}},$$

instead of

$$H(z) = \frac{-1 + 32z^{-16} + z^{-32}}{1 + z^{-1}}.$$

### 1.2.1 Design and analysis of filters

Manipulation

Edit the script `main_RPeakFilterAnalysis.m` to plot the frequency responses (gain and phase) of each filter used in the algorithm.
☞ Functions `freqz`, `phase` and `unwrap`.

**Comment** the figures and **justify** the choice of parameters values.
**Explain** why the term $z^{-2}$ is mandatory in the derivative filter (1).

### 1.2.2 Algorithm to detect R peaks

Manipulation

Edit the the script `main_RPeakDetection.m` to implement the algorithm [3] used to detect the R peak.
☞ Edit the function `ecgRPeakDetector`.
☞ Functions `peakDetector` and `simultaneousPeak`.

**Comment and explain** the results.

Plot the segmented beats, synchronized on the R peak. **Comment** the figure.
☞ Function `epoch`.

Compare the results provided by using

- only the signal after the full processing;
- only the band-pass filtered signal;
- both signals simultaneously.

# 2 Fetal ECG extraction

In this section, you will implement two complementary methods to extract fetal ECG from abdominal sensors: spatial filtering by periodic component analysis [4] and extended Kalman filtering applied on ECG denoising [5].

## 2.1 Spatial filtering: $\pi$CA

**Manipulation**

Edit the script `main_PiCA.m`:

- Load the matlab file `FetalECG.mat` (`Fs` is the sampling frequency and `x` is the ECG data).
- Filter the data to remove the baseline using a high-pass FIR filter whose transfer function is
$$H(z) = z^{-N} - \frac{1}{2N+1}\frac{1-z^{-(2N+1)}}{1-z^{-1}},$$
with $N$ a positive integer. **Justify** your choice of cutoff frequency.
- Implement the $\pi$CA algorithm.
☞ Function `periodicComponentAnalysis`.

**Comment** the results.

**Compare** the extracted components with these provided by PCA and ICA.
☞ Functions `eig` and `BSS` for PCA and ICA, respectively.

Do the same analysis using only a subset of channels.
**Comment** the results and compare them to those obtained using of all channels.

## 2.2 ECG denoising by extended Kalman filtering

**Explain** briefly the principle of the method detailed in [5] (available on Chamilo).
☞ Especially Sections II-A and IV-A to IV-D.

**Manipulation**

Edit the script `main_EKF.m`:

- Apply the $\pi$CA on the data as in the previous section;
- Select a component extracted by the $\pi$CA containing the fetal ECG;
- Apply on this component the extended Kalman filter (EKF).
☞ Function `extendedKalmanFilter_ECG` (see Appendix A for a short readme).

**Comment** the results.
Back project the fetal ECG estimation onto the channels. **Comment** the results.

Apply directly the EKF on a chosen channel after removing its baseline. **Comment** the results.

Why is it better to apply the EKF on a component extracted by $\pi$CA than directly on raw data (*i.e.* original signals)?

# A Use of function `extendedKalmanFilter_ECG`

This function apply the extended Kalman filter described in [5]. Its first estimates the shape of the mean ECG beat and then apply an extended Kalman filter to denoise it.

For the estimation of the mean beat a figure ("Mean ECG Beat") will appear to locate the approximative location of Gaussian function centers:

1. click on the main extrema;
2. click on the "Optimize" button;
3. if the mean ECG beat (in black) is well estimated then go to the next step, else click on the not well estimated parts and click on the "Optimze" button. Repeat this step until the mean ECG beat is well estimated;
4. click on the "Export parameters" button.

# References

[1] A. Matonia, J. Jezewski, T. Kupka, K. Horoba, J. Wrobel, and A. Gacek, "The influence of coincidence of fetal and maternal QRS complexes on fetal heart rate reliability," *Medical and Biological Engineering and Computing*, vol. 44, no. 5, pp. 393–403, 2006.

[2] A. L. Goldberger, L. A. N. Amaral, L. Glass, J. M. Hausdorff, P. C. Ivanov, R. G. Mark, J. E. Mietus, G. B. Moody, C.-K. Peng, and H. E. Stanley, "Physiobank, physiotoolkit, and physionet," *Circulation*, vol. 101, no. 23, pp. e215–e220, 2000.

[3] J. Pan and W. J. Tompkins, "A real-time QRS detection algorithm," *IEEE Transactions on Biomedical Engineering*, vol. BME-32, no. 3, pp. 230–236, March 1985.

[4] R. Sameni, C. Jutten, and M. B. Shamsollahi, "Multichannel electrocardiogram decomposition using periodic component analysis," *IEEE Transactions on Biomedical Engineering*, vol. 55, no. 8, pp. 1935–1940, Aug 2008.

[5] R. Sameni, M. B. Shamsollahi, C. Jutten, and G. D. Clifford, "A nonlinear bayesian filtering framework for ECG denoising," *IEEE Transactions on Biomedical Engineering*, vol. 54, no. 12, pp. 2172–2185, Dec 2007.