521273S Biosignal Processing I

Assignment 1. Respiration analysis

Deadline: Friday November 2nd at 10.00

Learning outcomes

- to become familiar with the basics of Matlab programming

In order to pass the exercise, all correctly executed task results must be personally presented to a course assistant during the scheduled lab consulting hours.

Background

Participate in the lecture on Tuesday October 30th

Respiratory effort belts are widely used to monitor respiration noninvasively and continuously. They are used for example in monitoring the respiration in sleep, detecting the functional disorders of the respiratory system, detecting the respiratory muscle dysfunctions and moreover they are comfortable and an easy way to monitor the respiration of children and infants. Additional advantage is that respiratory effort belts do not require the use of a face mask or mouth piece which could change the breathing pattern.

Without calibration respiratory belts give only qualitative information about the movement of the chest and abdomen. After calibration, they can be used quantitatively to measure continuous respiratory volume and airflow.

The respiratory system can be considered as a simple physical system with two moving parts: the chest and abdomen [1]. Consequently, the sum of the volume change of the chest and abdomen is equivalent to the volume measured at the mouth. This concept of two degrees forms the basis of the various techniques that can be used to calibrate the respiratory effort belts, for instance multiple linear regression.

A prediction of the respiratory airflow, F_{est}, is commonly calculated from the respiratory effort belt signals by using multiple linear regression [2] to a simultaneous spirometer recording. This baseline model can be established by fitting the following linear model to the time-synchronized signals:

$$F_{est} = \beta_1 s_{ch} + \beta_2 s_{ab} + \varepsilon$$

where the regressor variables s_{ch} and s_{ab} are the respiratory effort belt signals from the chest and abdomen, respectively, and ε is the zero-mean and Gaussian error. β_1 and β_2 are regression coefficients. In this baseline model, one sample of each regressor variable is used at a time to predict the response variable. This model can be extended to include more regressor variables if necessary, for example second order terms (s_{ch}^2 and s_{ab}^2) and/or cross-product term ($s_{ch}s_{ab}$).

Useful MATLAB commands:

```
load, resample, length, mean, sum, power, sqrt, figure, subplot,
plot, xlabel, ylabel, title, linspace, hold on, zeros
```

Data

Download data files ***spirometer.txt***, ***beltSignals.txt*** (includes chest (1. column) and abdomen (2. column) respiratory effort belt signals), ***regressionCoefficients1.txt, regressionCoefficients2.txt*** and ***regressionCoefficients3.txt*** from Noppa. Movements of the chest and abdomen were measured with the respiratory effort belts [au] (au = arbitrary unit). The spirometer was used to measure airflow signal [ml/s]. These signals were measured at the same time. Spirometer signal is already time-synchronized with the respiratory effort belt signals.
Sampling frequencies:

- respiratory effort belt signals 50Hz
- spirometer signal 100Hz

NOTE: In this first assignment, used signals are heavily filtered so that they would be smooth and algorithms would be easy to implement. In the real case, this kind of heavy filtering is not acceptable (distorts signals). Additionally, algorithms would be more complicated!

Exercise

Write your solution as a MATLAB script (m-file)!

- **Load** regression coefficients, spirometer signal and respiratory effort belt signals into MATLAB

- **Resample** spirometer signal to 50Hz.

- The used models were trained with the signals measured from the same person about 15 min before than signals given here. Regression coefficients from those trainings are now used with the given respiratory effort belt signals (*beltSignals.txt)* to produce predictions of respiratory airflow (F_{est1}, F_{est2} and F_{est3}). **Compute** predicted respiratory airflows with the following three models:

$$F_{est1} = \beta_1 s_{ch} + \beta_2 s_{ab} \tag{1}$$

$$F_{est2} = \beta_1 s_{ch} + \beta_2 s_{ab} + \beta_3 s_{ch}^2 + \beta_4 s_{ab}^2 \tag{2}$$

$$F_{est3} = \beta_1 s_{ch} + \beta_2 s_{ab} + \beta_3 s_{ch} s_{ab} \tag{3}$$

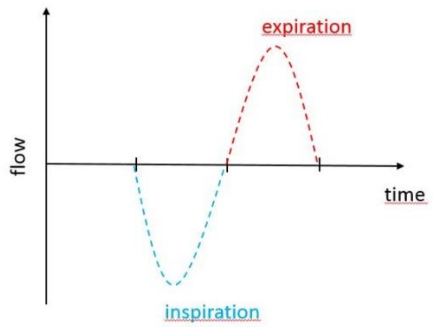
  Regression coefficients for the models are given in files *regressionCoefficients1.txt*, *regressionCoefficients2.txt* and *regressionCoefficients3.txt*, respectively.
  Hint: make an online search for “element-wise multiplication in MATLAB” (lmgtfy).

- **Evaluate** the adequacy of the predicted respiratory airflow signals:
  - Compute correlation coefficients (formula on the last page)
    - Hint: You can use `corrcoeff` function to verify your results
    - Comment: this task is only an exercise, the naive implementation has many practical drawbacks, thus `corrcoeff` function is implemented differently
  - Compute RMSE values (formula on the last page)
  - Which model gives the best results?

- **Plot** figure using `subplot` with 2x1 subplot matrix
  - top: spirometer airflow signal with black color, the first predicted respiratory airflow signal with red color, the second predicted respiratory airflow signal with blue color and the third predicted respiratory airflow signal with green color
  - bottom: chest signal with blue color and abdomen signal with green color
  - ensure that the x-axes are labeled in seconds and y-axes in suitable units
  - add informative titles to the subplots

Additional tasks (if you want to do more):

- **Implement an algorithm to compute** respiratory rate [breaths per minute] from spirometer signal
  - breath = inspiration + expiration (in this order)
  - inspiration is below and expiration is above zero line (figure below)
  - only include full breath cycles in your calculation



- **Implement an algorithm to compute** average duty cycle T_i / T_{tot} from spirometer signal
  - T_i = inspiratory time
  - $T_{tot} = T_i + T_e$
- **Implement an algorithm to compute** average T_{ptef} / T_e
  - T_{ptef} = time from the beginning of the expiration to the peak expiratory airflow
  - T_e = expiratory time

Correlation coefficient

To obtain a measure of fit, the correlation coefficient (r) can be computed with the formula

$$r^2 = \frac{[\sum_{n=1}^{n=N} x(n)y(n) - N\bar{x}\bar{y}]^2}{[\sum_{n=1}^{n=N} x^2(n) - N\bar{x}^2]\,[\sum_{n=1}^{n=N} y^2(n) - N\bar{y}^2]}$$

where N is the number of samples of x or y.
x represents the predicted respiratory airflow signal and y represents the spirometer airflow signal.
$\bar{x}$ is the mean of x and $\bar{y}$ is the mean of y.

Root mean square error RMSE

The formula of mean squared error (MSE) is

$$MSE = SS_{err} / n$$

SS_{err} is called the residual sum of squares. It is a measure of the variability in y (spirometer signal) remaining after regressor x has been considered. It's formula is

$$SS_{err} = \sum_i (y_i - f_i)^2$$

where f_i is the predicted respiratory airflow signal.

Root mean square error (RMSE) is the square root of MSE. It indicates the absolute fit of the model to the data, how close the observed data points are to the model's predicted values.

References

1. Konno K, Mead J (1967) Measurement of the separate changes of chest and abdomen during breathing. J Appl Physiol 22:407-422.
2. Montgomery DC, Peck EA, Vining GG (2001) Introduction to linear regression analysis. 3rd edition. John Wiley & Sons.