

Biosignal Processing

Assignment 1. Respiration analysis

LEARNING OUTCOMES

To become familiar with the basics of programming with biosignals.

BACKGROUND

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. An additional advantage is that respiratory effort belts do not require the use of a face mask or a mouthpiece that 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 ($s_{ch}s_{ab}$).

DATA

For this task, you need sample signals and precomputed regression coefficients provided for you by the teacher as the files *spirometer.txt*, *beltSignals.txt*, *regressionCoefficients1.txt*, *regressionCoefficients2.txt* and *regressionCoefficients3.txt*. The belt data file includes both the chest and the abdomen respiratory effort belt signals as columns, in this order.

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. The sampling frequencies of the signals were: 50 Hz for the respiratory effort belt signals, and 100 Hz for the spirometer signal.



EXERCISE

Implement the following computation steps in the selected programming language:

- **Load** regression coefficients, spirometer signal and respiratory effort belt signals.
- **Resample** spirometer signal to 50Hz.
- **Compute** predicted respiratory airflows with the following three models:

$$F_{est1} = \beta_1 s_{ch} + \beta_2 s_{ab} \quad (1)$$

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

$$F_{est3} = \beta_1 s_{ch} + \beta_2 s_{ab} + \beta_3 s_{ch} s_{ab} \quad (3)$$

These models were trained with the signals measured from the same person about 15 min before than signals given here. The resulting 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}). The regression coefficients for the models are given in files *regressionCoefficients1.txt*, *regressionCoefficients2.txt* and *regressionCoefficients3.txt*, respectively.

- **Evaluate** the adequacy of the predicted respiratory airflow signals:
 - Compute correlation coefficients (see the end on the last instructions)
 - Compute RMSE values (see the end on the last instructions)
 - Which model gives the best results?
- **Plot** the results in a figure with two subfigures vertically:
 - 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

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

$$\text{MSE} = \text{SS}_{\text{err}} / n.$$



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.

