PCA_for_FetalECG

November 26, 2024

1 PCA for Source Separation of Abdominal ECG Signals

1.1 Introduction

In this exercise we use PCA for the separation of maternal and fetal electrocardiography (ECG) signals in abdominal ECG (aECG) data recorded on the belly of a pregnant woman. Due to the low signal strengh of fetal ECG (fECG) signals it is an "algorithmic challenge" to properly separate fECG from much stronger maternal ECG (mECG) signals [1].

The present example uses a simplified version of the method proposed by Varanini et al. [2].

1.2 References

[1] R. Kahankova et al., "A Review of Signal Processing Techniques for Non-Invasive Fetal Electrocardiography," IEEE Reviews in Biomedical Engineering, vol. 13, pp. 51–73, 2020, doi: 10.1109/RBME.2019.2938061.

[2] M. Varanini, G. Tartarisco, L. Billeci, A. Macerata, G. Pioggia, and R. Balocchi, "An efficient unsupervised fetal QRS complex detection from abdominal maternal ECG," Physiol. Meas., vol. 35, no. 8, pp. 1607–1619, Aug. 2014, doi: 10.1088/0967-3334/35/8/1607.

[3] Source of data: https://physionet.org/content/challenge-2013/1.0.0/

[1]:
```python
import numpy as np
import pandas as pd
from scipy.signal import filtfilt, butter
from sklearn.decomposition import PCA

import plotly.graph_objects as go
from plotly.offline import init_notebook_mode, iplot
from plotly.subplots import make_subplots
init_notebook_mode(connected=True)  # initiate notebook for offline plot

from mqrs_utils import cancel_mqrs
from ecgdetectors import Detectors
```

[2]:
```python
# load abdominal ECG (aECG) data
# transformed from initial source: https://physionet.org/content/challenge-2013/
 ↪1.0.0/set-a/a13.dat
filename = 'aecg_a13.hdf5'
```

```
aecg = pd.read_hdf(filename, key='signals').values
fs = 1000
t = np.arange(aecg.shape[0]) / fs
```

[3]:
```
# bandpass filter data
b, a = butter(4, np.asarray([3, 45]), fs=fs, btype='bandpass')
aecg = filtfilt(b, a, aecg, axis=0)

# plot
fig = go.Figure()
for i in range(aecg.shape[1]):
    fig.add_trace(go.Scatter(x=t, y=aecg[:, i], name='AECG{:d}'.format(i)))
fig.update_xaxes(title='Time (s)')
fig.update_yaxes(title='AECG Amplitude (A.U.)')
fig.update_layout(title='Bandpass-Filtered AECG Signals')
fig.show()
```

[4]:
```
# apply first PCA for enhancing maternal ECG component
pca1 = PCA()
pc1 = pca1.fit_transform(aecg)

# maternal ECG as the first principal component, note that this
# remains a guess and would need to be automated in the final solution
maternal_ecg = pc1[:, 0]

# detect maternal QRS peaks
mqrs_peaks = Detectors(fs).engzee_detector(maternal_ecg)

# plot
fig = go.Figure()
for i in range(pc1.shape[1]):
    fig.add_trace(go.Scatter(x=t, y=pc1[:, i], name='PC1[:,{:d}]'.format(i)))
    if i == 0:
        fig.add_trace(go.Scatter(x=t[mqrs_peaks], y=pc1[mqrs_peaks, i],␣
 ↪name='mQRS-Peaks',
                                 mode='markers', marker_color='red',␣
 ↪marker_symbol='circle-open'))
fig.update_xaxes(title='Time (s)')
fig.update_yaxes(title='PC1 (A.U.)')
fig.update_layout(title='Principal Components of First PCA Used to Enhance mECG␣
 ↪Signal')
fig.show()
```

[5]:
```
# remove maternal QRS complexes from signal to obtain a best possible fetal ECG␣
 ↪signal
x_residual, mecg_estimations = cancel_mqrs(fs, pc1, np.asarray(mqrs_peaks))
```

```
# plot
fig = make_subplots(rows=3, cols=1, shared_xaxes=True)
fig.add_trace(go.Scatter(x=t, y=pc1[:,0], name='Maternal ECG'), row=1, col=1)
fig.add_trace(go.Scatter(x=t[mqrs_peaks], y=pc1[mqrs_peaks, 0],␣
 ↪name='mQRS-Peaks', marker_color='red',
                         legendgroup='mQRS', mode='markers',␣
 ↪marker_symbol='circle-open'), row=1, col=1)
fig.add_trace(go.Scatter(x=t, y=mecg_estimations[:, 0], name='Interpolated mQRS␣
 ↪Signal'), row=2, col=1)
fig.add_trace(go.Scatter(x=t[mqrs_peaks], y=mecg_estimations[mqrs_peaks, 0],␣
 ↪name='mQRS-Peaks', marker_color='red',
                         legendgroup='mQRS', showlegend=False, mode='markers',␣
 ↪marker_symbol='circle-open'), row=2, col=1)
fig.add_trace(go.Scatter(x=t, y=x_residual[:, 0], name='mQRS-free Signal'),␣
 ↪row=3, col=1)
fig.add_trace(go.Scatter(x=t[mqrs_peaks], y=x_residual[mqrs_peaks, 0],␣
 ↪name='mQRS-Peaks', marker_color='red',
                         legendgroup='mQRS', showlegend=False, mode='markers',␣
 ↪marker_symbol='circle-open'), row=3, col=1)
fig.update_xaxes(title='Time (s)', row=3, col=1)
fig.update_layout(title='Maternal QRS Cancellation')
fig.show()
```

[6]:

```
# apply second PCA for enhancing fetal ECG component in residual signal
pca2 = PCA()
pc2 = pca2.fit_transform(x_residual)

# fetal ECG as the first principal component, note that this
# remains a guess and would need to be automated in the final solution
fetal_ecg = pc2[:, 0]
# detect fetal QRS peaks
fqrs_peaks = Detectors(fs).engzee_detector(fetal_ecg)

# plot
fig = go.Figure()
for i in range(pc2.shape[1]):
    fig.add_trace(go.Scatter(x=t, y=pc2[:, i], name='PC2[:,{:d}]'.format(i)))
    if i == 0:
        fig.add_trace(go.Scatter(x=t[fqrs_peaks], y=pc2[fqrs_peaks, i],␣
 ↪name='fQRS-Peaks',
                                 mode='markers', marker_color='black',␣
 ↪marker_symbol='triangle-down-open'))
fig.update_xaxes(title='Time (s)')
fig.update_yaxes(title='PC2 (A.U.)')
fig.update_layout(title='Principal Components of Second PCA Used to Enhance␣
 ↪fECG Signal')
```

```
fig.show()
```

[7]:
```
# plot for summarizing all
fig = make_subplots(rows=2, cols=1, shared_xaxes=True)
# maternal ECG with mQRS
fig.add_trace(go.Scatter(x=t, y=maternal_ecg, name='Maternal ECG'), row=1,␣
 ↪col=1)
fig.add_trace(go.Scatter(x=t[mqrs_peaks], y=maternal_ecg[mqrs_peaks],␣
 ↪name='mQRS-Peaks',
                         marker_color='red', mode='markers',␣
 ↪marker_symbol='circle-open'), row=1, col=1)
# fetal ECG with fQRS
fig.add_trace(go.Scatter(x=t, y=fetal_ecg, name='Fetal ECG'), row=2, col=1)
fig.add_trace(go.Scatter(x=t[fqrs_peaks], y=fetal_ecg[fqrs_peaks],␣
 ↪name='fQRS-Peaks',
                         marker_color='black', mode='markers',␣
 ↪marker_symbol='triangle-down-open'), row=2, col=1)
fig.update_xaxes(title='Time (s)', row=2, col=1)
fig.update_layout(title='Maternal vs. Fetal ECG')
fig.show()
```

2 Exercise Questions

Please provide your answers directly below each question.

2.1 Question 1

Determine the maternal heart rate, both expressed in `Hz` and `beats/min`.

[8]:
```
mqrs_peaks_t =  np.array(mqrs_peaks)/ fs
mean_hrb = np.mean(1 / np.diff(mqrs_peaks_t))

print('Mean Heart Rate of Maternal ECG: {:.2f} Hz'.format(mean_hrb))
print('Mean Heart Rate of Maternal ECG: {:.2f} bpm'.format(60*mean_hrb))
```

```
Mean Heart Rate of Maternal ECG: 1.37 Hz
Mean Heart Rate of Maternal ECG: 82.08 bpm
```

2.2 Question 2

Determine the fetal heart rate, both expressed in `Hz` and `beats/min`.

[9]:
```
fqrs_peaks_t =  np.array(fqrs_peaks)/ fs
mean_hrb = np.mean(1 / np.diff(fqrs_peaks_t))

print('Mean Heart Rate of Fetal ECG: {:.3f} Hz'.format(mean_hrb))
print('Mean Heart Rate of Fetal ECG: {:.3f} bpm'.format(60*mean_hrb))
```

```
Mean Heart Rate of Fetal ECG: 1.914 Hz
Mean Heart Rate of Fetal ECG: 114.860 bpm
```

2.3 Question 3

Determine the follwing three values:

- i) the average amplitude of the maternal QRS peaks (`mQRS`);
- ii) the average amplitude of the fetal QRS peaks (`fQRS`);
- iii) the ratio between the average amplitudes of i) `mQRS` and ii) `fQRS` peaks.

[10]:
```
avg_mqrs = np.mean(maternal_ecg[mqrs_peaks])
avg_fqrs = np.mean(fetal_ecg[fqrs_peaks])
ratio_fm = avg_fqrs / avg_mqrs
ratio_mf = avg_mqrs / avg_fqrs
print('Average amplitude of the maternal QRS complexes: {:.3f}'.
  ↪format(avg_mqrs))
print('Average amplitude of the fetal QRS complexes: {:.3f}'.format(avg_fqrs))
print('Ratio of fetal to maternal QRS complex amplitudes: {:.3f}'.
  ↪format(ratio_fm))
print('Ratio of maternal to fetal QRS complex amplitudes: {:.3f}'.
  ↪format(ratio_mf))
```

```
Average amplitude of the maternal QRS complexes: 103.253
Average amplitude of the fetal QRS complexes: 20.496
Ratio of fetal to maternal QRS complex amplitudes: 0.199
Ratio of maternal to fetal QRS complex amplitudes: 5.038
```

2.4 Question 4

How many of the principal components of the first PCA clearly show a maternal ECG signal? Which ones?

From the *Principal Components of First PCA Used to Enhance mECG Signal* plot, we can see that the two first components of the PCA (PC1[0:] and PC1[1:]) contains the ECG of the mother. The other two are not significant for the ECG.

2.5 Question 5

How many of the principal components of the second PCA clearly show a fetal ECG signal? Which ones?

For the fetal, only the first PCA component is relevant. It can be seen in the *Principal Components of Second PCA Used to Enhance fECG Signal* plot. The other three remaining components contain noises.

2.6 Question 6

Not all of the fetal QRS peaks seem to be detected properly. Do you have an explanation why this happens and under which circumstances? Is it a problem of the fQRS detector, the mQRS cancellation or of another block of the algorithm?

It can be seen that the fQRS peak detector fails to find all the relevant peaks. It often happens when the peak is close to a mQRS peak. It can be due to the fact that applying mQRS cancellation will also remove parts of the fetal ECG signal.