Obstructive Sleep Apnea analysis based on heart rate variability

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Abstract—In this project we compared features in time segments of the heart rate to distinguish obstructive sleep apnea (OSA) from ‘normal’ sleep segments. The time duration of the segments is 5 minutes and features include estimates of the autocorrelation function (ACF), partial autocorrelation function (PACF), and power spectral density (PSD).

In the OSA segments PSD estimator did not resolve the apnea breath/cessation cycles of the ensemble average, instead, shows a higher PSD in the apnea frequency band range (0.01-0.04 Hz). The ACF decays rapidly in a ‘normal’ sleep segments, while in the apnea segments the cycles were shown as a decaying sinusoid. The presence of only two major peaks in the PACF at 1 and 2 seconds lags indicates both apnea and ‘normal’ sleep processes have equal memory.

Index Terms—Autocorrelation function, Obstructive sleep apnea, partial autocorrelation function, power spectral estimation.

I. INTRODUCTION
Sleep apnea is a disorder that commonly affects more than 12 million people in the United States. It takes its name from the Greek word apnea, which means "without breath." People with sleep apnea literally stop breathing repeatedly during their sleep, often for a minute or longer and as many as hundreds of times during a single night. Sleep apnea can be caused by either complete obstruction of the airway (obstructive apnea) or partial obstruction (obstructive hypopnea-- hypopnea is slow, shallow breathing), both of which can wake one up. There are three types of sleep apnea — obstructive, central, and mixed. Of these, obstructive sleep apnea (OSA) is the most common. OSA occurs in approximately 2 percent of women and 4 percent of men over the age of 35 and it is the main focus in this work.

Obstructive Sleep Apnea represents a major, yet mostly unrecognized nighttime disease. It is associated with a wide range of health implications and increased cardiovascular morbidity and mortality. The gold standard in diagnosing OSA is polysomnographic, an inconvenient, expensive and time consuming procedure which includes an overnight multi channel recording of respiratory and other vital parameters in a specialized sleeping laboratory. An effective and inexpensive screening is highly desirable.

Detection based on only ECG signal relies on the abnormalities in the heart rate variability, which is related to the periodic cycles of breathing cessation and restoration. These patterns should be identified through the PSD analysis of the heart rate signal. Many researchers [1, 2, 3] have confirmed the fact that sleep-disordered breathing can be achieved by making use of several distinctive features of heart rate oscillation associated with sleep apnea.

The objective of this project is to analyze and compare estimates of the PSD, ACF, and the PACF between ‘normal’ sleep and OSA segments of the heart rate. Segments could have different durations. This project will analyze the ECG features related to five-minute segments’ duration.

In many cases people might suffer OSA without being aware of their illness. Therefore, the significance of attaining the objective will result in an easy and less expensive method to diagnose OSA based only on the ECG signal.

II. METHODOLOGY

A. Preprocessing data
Data is supplied by Physionet database of CinC challenge 2000 [4] and consist of 70 ECG signals of around 8hrs duration each, sampled at frequency 100 Hz, 12-bit amplitude resolution. Signals are divided into two groups; training set and test set, each set consist of 35 records. The training set records are annotated minute by minute, 20 records are from patients suffering OSA (class A), 5 from borderline (class B) and 10 from ‘normal’ individuals (class C). A human expert, on the basis of simultaneously analyzing ECG and the recorded respiration signals, made the annotations.

In this project we will use records from the training set using signals from the three different classes. The ECG signals were preprocessed and the R-R times were extracted by the implementation of a QRS detector made by Dr. James McNames.

B. Procedure
In the following analysis the mean was extracted from each segment prior to processing. The first parameter to estimate is
the instantaneous HR since all other features will be based on its values.

1. R-R to HR conversion
   The conversion from R-R intervals into instantaneous heart rate is implemented using the low-pass Gaussian filter shown in Fig.1. The filter has standard deviation $\sigma = 3$ seconds and 27 seconds duration. The sampling frequency used is 1 Hz; the filter input is the R-R intervals and its output the instantaneous HR in beat/min. The filter cutoff frequency is 0.0438 Hz, which will include the apnea frequency band (0.01-0.04 Hz).

2. Autocorrelation function (ACF)
   The estimate of the autocorrelation is implemented using the biased estimate given by [5]:
   \[ \hat{r}(l) = \frac{1}{N} \sum_{n=0}^{N-1-l} x(n+l)x^*(n) \]
   \[ \hat{r}(l) = \begin{cases} r^*(-l) & 0 \leq l \leq N-1 \\ 0 & (N-1) \leq l < 0 \end{cases} \]
   It is semi-definite positive estimator, which has smaller variance and less MSE than the biased estimator.

3. Partial Autocorrelation function (PACF). Estimate is based on the use of Levinson-Durbin algorithm.

4. Power Spectral Density (PSD). For comparison purposes an estimate for a whole record is done using all three methods, smoothed periodogram, Blackman-Tukey, and Welch-Bartlett. Segments’ PSD estimates are implemented using the Welch-Bartlett technique.

III. DISCUSSION
   The estimation techniques applied in this study are based on ‘stationary process’ assumption. The HR segments we have considered are the different realizations of a stochastic process. The biological process that produces the heart rate time series is not stationary and therefore is not Ergodic. However, the process can be considered locally stationary over short time segments during which the mechanisms responsible for heart rate modulation are assumed to remain unchanged. Time series used in this study are short enough to justify the assumption of a ‘local stationary’ process. However, the process is not Ergodic.

Comparison of the heart rate between ‘normal’ and OSA sleep patterns are shown in Figures 2, 3. These figures show HR patterns for same record. A ‘normal’ sleep heart rate pattern contain no consistent ‘uniform’ cycles as shown in Figure 2 for record c05 and the top row of figures of Figure 3 for records a01 and b01 respectively. In contrast, consistent cycles of heart rate patterns with frequency of 5 cycles every 6 minutes are clearly shown for records a01 and b01 in the bottom row of Figure 3.
method. The first two rows should show similar results but because of the different window sizes used they have different characteristics. The characteristic of all these estimates is the presence of two peaks at 0.014 Hz and 0.022 Hz for records with OSA.

Comparison between OSA and ‘normal’ sleep segments is shown in Figure 5 for a01 and Figure 6, 7 for b01 and c05 respectively. The sleep apnea cycles are shown in the ensemble average plots for record a01. The 90% confidence band follows tightly the ensemble average plot thanks to the many apnea episodes in this record with relatively long duration. The oscillation and slow decay of the ACF in the ‘normal’ sleep segments is due to its limited number and time duration in this record. Record c05 does not contain OSA segment, as a result the ACF ensemble average does not contain cycles and decays rapidly as shown in Figure 7. There is a comparable number of apnea and ‘normal’ segments for record b01 thus the ACF and PSD estimates is a case in between the above two as shown in Figure 6. The common characteristic of the PACF estimates for the cases is to have two impulses at lags 1 and 2 seconds suggesting same memory processes for both OSA and ‘normal’ segments. In all cases, PSD estimator does not distinguish the apnea peaks; a better window and parameter selection should be searched. However, the power is clearly higher in the apnea frequency range for apnea segments than normal segments.

Figure 4. Full record PSD estimates using three different techniques, Averaged periodogram (A-P), Blackman-Tukey (B-T), and Welch-Blackman (W-B) applied on records a01, b01, and c05.

Figure 5. Five-minute segments from file a01, confidence bands 90%. The first column is for apnea segment while the second for normal sleep segment.

Figure 6. Five-minute segments from file b01, confidence bands 90%. The first column apnea segments while the second and third column for normal sleep.

Figure 7. Five-minute segments from file c05, confidence bands 90%. The record does not contain apnea segments.
IV. RESULTS

The ACF estimator performs well as shown in Figure 5 for apnea segments where the 90% confidence band follows ‘tightly’ the ensemble average. In this case the segmented heart rate was mostly composed of apnea related heart rate as a result the estimator has enough data to perform successfully and scores the apnea cycles. In the other hand the number of ‘normal’ segments in this record is relatively small as a result we see the high fluctuations in the confidence band and the rough ensemble average of the ACF. The PACF estimator in all cases performs well as shown in Figures (5-7), the confidence band follows tightly the ensemble averages.

The three techniques of PSD estimators match on the presence of two peaks at 0.014 Hz and 0.022 Hz with good frequency resolution. When applying Welch-Bartlett PSD estimator method on HR segments the apnea peaks were not resolved as shown in Figures (5-7), instead a higher PSD than the normal sleep segments in the frequency apnea range.

V. CONCLUSION

In this project we compared features in time segments of the heart rate to distinguish obstructive sleep apnea (OSA) from normal sleep segments. The time duration of the segments was 5 minutes and features include estimates of the autocorrelation function (ACF), partial autocorrelation function (PACF), and power spectral density (PSD).

The PSD estimator did not resolve peaks due to apnea cycles when applied to apnea HR segments, instead only shows a higher PSD in the apnea frequency band range (0.01-0.04 Hz). The ACF estimator performs well when there is enough data. The ACF decays rapidly in a normal sleep segments, while in the apnea segments the breath/cessation cycles were shown as a decaying sinusoid. The presence of two major peaks in the PACF at 1 and 2 seconds lags for both processes suggests that both processes have same memory.

REFERENCES

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