Sleep Apnea Detection using Heart Rate Variability and Classifiers

Humaira Batool
Department of Electrical Engineering, UET Taxila, Taxila, Pakistan

Abstract-The Obstructive Sleep Apnea (OSA) or Obstructive Sleep Apnea Syndrome (OSAS) is the sleeping disorder causing the pause in breathing process or a very low breathing rate while sleeping. The standard technique for analyzing Obstructive Sleep Apnea is called Polysomnography (PSG), which needs an overnight stay in sleep Labs, which is very costly and inconvenient. Alternatively Electrocardiogram (ECG) signal is very promising for OSA detection. An automated classification algorithm is presented in this paper which can deal with short time duration data of an ECG Signal Heart Rate Variability (HRV), from which temporal features are extracted and these extracted features are used in classification. The classification technique being used is based on Support Vector Machine (SVM), trained and tested for data taken from Physionet.org. Resulting algorithm has a high accuracy up to 86.025% and a less processing time.

Keywords: Sleep Apnea Disorder, ECG, HRV, Classification, SVM

1. INTRODUCTION

1.1. Background

In life, humans sleep about one-third of their lives. A terrible feeling appears and body reminds us the essence of sleep, if a long time has been spent without sleep. Such as eating, drinking are the necessities of life, a proper / sound sleep is also the requirement for our body to be healthy and active in life.

The Sleep disorder happens when one can’t sleep properly. About seventy different types of sleeping disorder exist, which are divided in to following three categories [1]

- Excessive drowsiness (e.g. narcolepsy).
- Lack of sleep (e.g. insomnia).
- Sleep disorders (e.g. sleep apnea).

The sleep disorder causing repeatedly breathing problem (stops and starts) during sleep is called Sleep Apnea. Several types of sleep apnea exist, but the most common type is obstructive sleep apnea. Obstructive sleep happens when someone’s throat muscles irregularly relax and blocks airway during sleep. The most noticeable sign of obstructive sleep apnea is snoring. Anyone can develop obstructive sleep apnea, although it mostly affects middle-aged, older adults and people who are overweight [2]. Although sleep Apnea is very common, it remains undiagnosed in 90% people having apnea.

The Standard method / technique or approach that is used to detect Sleep Apnea is called Polysomnography (PSG). Polysomnography is based on the comprehensive monitoring of cardio respiratory and sleep signals. Polysomnography needs an overnight stay at hospital that may be inconvenient and uncomfortable experience for individuals because it disturbs or inhibits normal sleep and is often expensive.

On the other hand, the ECG signal is very promising for OSA detection, as it offers a more convenient data collection procedure, in this research we are using ECG signals time domain features in order to find out the Sleep Apnea. [3]

1.2. Methodology of Research

The organization of research is as follows, Section II is containing the study of previously deployed methods for detection of apnea using ECG signals, Section III is dealing with the implementation of proposed methodology, Section IV with results and Section V with Conclusion

2. RELATED WORK

ECG provides an alternative view of physiological changes related to sleep apnea / dangerous behavior. In 2000, the organizers of the warehouse database Physionet realized the importance and the possibility of the use of ECG signals in the diagnosis of sleep apnea. As a result, a challenge was organized, where teams of researchers made a number of different researches for the detection of sleep apnea with ECG signals only [4]. Since then, several methods for the diagnosis of OSA have been developed using the ECG signal.

Manrique Quiceno, Manizales, J.B. Hernandez Alonso, C.M. Gonzalez Travieso presented the idea to access the heart rate variability by means of time - frequency analysis implemented with time - frequency distribution belonging to Cohen’s Class [5]. The accuracy obtained in this method was high up to 75%.

N. Selvaraj, R. Narasimhan presented the idea for detection of Apnea on per second basis using respiratory signals [6]. The idea presented this research was the use extracted features of an ECG signal, based on filtering and statistical scattering of the nasal airflow respiration signal and detected apnea events on a per-second basis. The accuracy of the system was low up to the level 64.30%.

Obstructive Sleep Apnea detection using SVM based classification of ECG signal features suggested by
L. Almazaydeh, K. Elleithy, M. Faezipour focused on an automated classification algorithm which could process short duration epochs of the electrocardiogram (ECG) data [7]. The presented classification technique was based on Support Vector Machines (SVM) and had been trained and tested on sleep apnea recordings from subjects with and without OSA. The results showed that automated classification system was able to recognize eras of sleep disorders with a high accuracy of 84.23% or higher.

Another method used was the introduction of system that utilized a band-pass filter to filter out components with extreme low and high frequencies from the Electroencephalogram (EEG) [8] presented by Avci and Akbas. It only conserved sleep-related bands from 0.5 to 32Hz. Moreover, it extracts frequency elements from Hilbert spectra by Hilbert-Huang transformation. The system computed four Hilbert spectra frequency intensities of the alpha, beta, theta, and delta signal from the transformed spectra. The system then detected duration of obstructive sleep apnea from the frequency variation. The experimental results showed that system could detect the duration of OSA as well as preserve time information in the electroencephalogram by Hilbert-Huang transformation mechanism and find frequency variation information. The main drawback of this system was unknown change of EEG or noise disturbance at some particular time.

Parallel Particle Swarm Optimization (PSO) – State Vector Machine (SVM) algorithm was proposed to detect sleep apnea[9]. It was based on three input signals (airflow, abdominal and throat movements) to the proposed algorithm. This algorithm consisted of three main parts; signal segmentation, feature generation, and classification. Complexity of algorithm and less efficient results were the drawbacks of this algorithm.

A new approach is suggested in this research by conflating of RR-interval created features of the ECG signal. Performance assessment of this method was done by measuring the classification performance for determining the occurrence of apnea. Support Vector Machines (SVMs) were used as a classification method (also known as supervised learning) in order to investigate apneic epoch detection.

### 3. METHODOLOGY

The use of the extracted features of an Electrocardiogram (ECG) for the detection of Obstructive Sleep Apnea is the basic motivation of this research. The block / plan diagram followed during this research is described in Figure 1

#### 3.1. Electrocardiogram (ECG) Signal

PhysioNet.org is a website that is an open source and has a free access publically that contains ECG database for different diseases including Apnea – ECG dataset. ECG signals used in this study are imported from PhysioNet.org. Apnea – ECG database of PhysioNet.org consists of Seventy (70) records of ECG data of apneic patients. These signals are varying in time duration length, from little less than 07 hours to round about 10 hours. Each ECG signal is sampled at 100 Hz sampling frequency having an accuracy of 16-bit, each sample bit is expressing 5μV. For preparation of this database the standard sleep laboratory Electrocardiogram poles were used [10]. A number of Statistics files are attached with each record, and number of functions can be performed including exporting the file in MATLAB supporting format [4].

#### 3.2. Data Preparation:

For the detection of Apneic ECG beats an ECG records with constant apnea data / record for a long / measurable period of
time has to be selected as normal data, followed by an apneic data demonstration for a particular period of time, or vice versa. This record on later stages is used by Support Vector Machine classifier in order to test datasets

3.3. Detecting R – Peaks

R – Wave of an ECG is the representation of electrical stimulus as blood passes through main portion of the ventricular walls, as this portion is more thick so R – Wave is much larger than others[9]. Our basic purpose is to distinguish R – waves from other waves, then to compute RR – Interval, as we are dealing with Temporal Features only. Time difference between two consecutive R – Waves is known as RR - Interval. Therefore, the first part of proposed algorithm is written to extract the R - wave from other waves of ECG signal.

There are two mandatory conditions that must be met in order to detect R-peak. If both of these conditions are fulfilled as given below the peak / wave will be identified / distinguished as R – Wave.

- A wave having a local extreme / Maxima within a window of 200ms.
- Value of the spotted local maxima / peak is 10 times greater than the mean value.

Once the R-peak has been detected, RR – interval is driven out as given below.

\[ rr=rr(i+1)-r(i) \]

3.4. Extracting Features of an ECG signal

Heart Rate Variability in time domains have been observed in this research. The basic purpose behind this algorithm development is to have a powerful combination of the features of an ECG signal so that a user friendly algorithm with more accurate results and less processing time can be developed. Following most effective features for the detection of apnea, in the time domain are used.

- Mean epoch and recording R-R interval
- Variance of the epoch and recording R-R interval
- Median epoch and recording R-R interval
- Ratio of 2 consequent R-R intervals
- Ratio of consequent five R-R intervals

3.5. Support Vector Machine Classification (SVM)

Support Vector Machine or SVM basically belongs the Machine Learning which is a field of Computer Sciences, idea of which was evolved basically from the pattern recognition study and computational learning theory in artificial intelligence [10].

Following are the steps to be followed in order to prepare data for Support Vector Machine according to [11]:

- Converting data into the format of an SVM package.
- An m by 1 vector with a label of training.
- An m by n matrix with n features of training instances
- An m by n matrix with n features of testing instances
- An m vector for prediction labels.
- Features Categorization
- Finding out best parameters C and Gamma by using cross-validation.
- Use the best parameter C and Gamma to train the whole training set
- Test

4. PERFORMANCE EVALUATION

The efficiency of this applied model on the Apnea-ECG database is evaluated, by using different records available in PhysioBank Apnea – ECG database. The model is applied using MATLAB. Two statistical indicators, Sensitivity, Specificity in addition to the Accuracy (Acc) have been used to evaluate the performance of applied system, processing time has also been considered in performance evaluation.

Accuracy: The Accuracy of a test is the percentage of patients in the positive group correctly analyzed / diagnosed.

\[ \text{Sensitivity} = \frac{\text{Number of Apneic Beats Diagnosed}}{\text{Number of Apneic Beats in dataset}} \times 100 \]

\[ \text{Specificity} = \frac{\text{Number of healthy Beats Diagnosed}}{\text{Number of healthy Beats in dataset}} \times 100 \]

An overview of results is shown in table 1:

- 80% of data for training phase and 20% for testing phase
- Time Domain features
• SVM parameters: C=2, γ =0
### Table 1 Result of Proposed Algorithm

<table>
<thead>
<tr>
<th>SVM</th>
<th>Avg. Sensitivity %</th>
<th>Avg. Specificity %</th>
<th>Avg. Accuracy %</th>
<th>Avg. Resp. time (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polynomial Kernel Degree 3</td>
<td>93.17</td>
<td>88.65</td>
<td>85.10</td>
<td></td>
</tr>
<tr>
<td>Polynomial Kernel Degree 4</td>
<td>93.66</td>
<td>81.24</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Radial Basis SVM</td>
<td>84.11</td>
<td>80.09</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Quadratic Kernel</td>
<td>91.22</td>
<td>90.54</td>
<td>83</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2 Results compared with other techniques

<table>
<thead>
<tr>
<th>Approach</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection of obstructive sleep apnea in ECG recordings using time-frequency distributions and dynamic Features [5]</td>
<td>69.64</td>
<td>44.44</td>
<td>75%</td>
</tr>
<tr>
<td>An Automated Sleep Apnea Detection Using Respiratory Signals on per second Basis [6]</td>
<td>100</td>
<td>80</td>
<td>64.30%</td>
</tr>
<tr>
<td>Sleep Apnea Detection From Heart rate Variability data using DWPT based technique [7]</td>
<td>97.8</td>
<td>88</td>
<td>84.23%</td>
</tr>
<tr>
<td>A novel partially connected cooperative parallel PSO-SVM algorithm: Study Sleep based on Sleep apnea detection [8]</td>
<td>88%</td>
<td>84.9%</td>
<td>81%</td>
</tr>
<tr>
<td>Real-Time Sleep Apnea Detection By Classifier Combination [9]</td>
<td>91%</td>
<td>83.2%</td>
<td>83.5%</td>
</tr>
<tr>
<td>Feature extraction of ECG signal (proposed Algorithm)</td>
<td>90.54%</td>
<td>85.13%</td>
<td>86.025%</td>
</tr>
</tbody>
</table>

- Cross validation Accuracy 71.65%
- 35 datasets are analyzed with each data
- Set containing 100 samples that is 3500 samples were analyzed.
- Four datasets are used in this algorithm testing a01~a15, b01~b05, c01~c05, x01~x10.
- Results are plotted in the form of confusion matrix.

### 5. Conclusion

In this research, we have the results of the detection of apneic heart beats in sleep apnea events from the ECG signal variation patterns during sleep. Moreover the ECG signal features are
used to develop a model its performance is evaluated. This research method is based on a selective set of RR-interval time-based domain features that are given to an SVM for classification for training and testing. Table 2 represents comparative results. It is evident from the results that, this research system has accomplished an equivalent or better performance (90.54% Sensitivity, 85.13% Specificity, and 86.025% Accuracy). This applies to the other works that rely on the ECG signal as well as other biometric signals. As a future work, a model to predict Sleep Apnea from ECG signals during sleep can be developed with 100% accuracy.

REFERENCES

[1] Sleep Disorder Definition and Types available online at http://www.healthcommunities.com/sleep-disorders/overviewsleepdisorders.shtml


