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Original Research Article

Computer-aided obstructive sleep apnea screening from single-lead electrocardiogram using statistical and spectral features and bootstrap aggregating

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ABSTRACT

Automatic sleep apnea screening is important to alleviate the onus of the physicians of analyzing a large volume of data visually. Again, the push towards low-power, portable and wearable sleep quality monitoring systems necessitates the use of minimum number of recording channels to enhance battery life. So, there is a dire need of an automated apnea detection scheme based on single-lead electrocardiogram (ECG). Most of the existing works are based on multiple channels of physiological signals or yield poor performance. The effect of various classification models on algorithmic performance is also poorly explored. In the present work, we propose a statistical and spectral feature based sleep apnea identification scheme that utilizes single-lead ECG signals. Bootstrap aggregating is employed to perform classification. The efficacy of the selected features is demonstrated by intuitive, statistical and graphical analyses. Optimal choices of classifier parameters are also expounded. The performance of the proposed algorithm is evaluated for various classifiers. The performance of our method is also compared to that of the state-of-the-art ones. The proposed method yields accuracy, sensitivity and specificity of 85.97%, 84.14% and 86.83% respectively on a widely used benchmark data-set. Experimental findings backed by statistical and graphical analyses suggest that the proposed method performs better than the existing ones in terms of accuracy, sensitivity, specificity and computational cost.

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1. Introduction

Obstructive sleep apnea (OSA) is a form of sleep-disordered breathing that is characterized by repetitive cycles of partial (hypopnea) or complete (apnea) collapse of the pharyngeal airway [1]. It affects about 10% of middle aged adults, primarily overweight or obese men. If untreated, OSA can cause somnolence, cognitive impairment, ischemic heart disease and cardiovascular morbidity and mortality. Nevertheless, nearly 80% of people with such condition remain undiagnosed and therefore untreated due to various

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problems associated with the present diagnostic technique [2].

Traditionally, OSA is diagnosed by expert physicians by manual observation of polysomnography (PSG) signals. OSA screening based on visual inspection is problematic because of two reasons. First, PSG is expensive and necessitates the subject to sleep in a specially equipped sleep center. Due to the unfamiliar environment of the sleep center, the subject's quality of sleep is degraded. Second, manual screening of OSA is onerous, time-consuming, reliant on expensive human resources, physicians level of expertise and experience and error-prone due to fatigue. In sleep research, on the other hand, due to the need of human intervention, visual OSA detection cannot scale to handle very large datasets which greatly hinders sleep apnea research. So there is a dire need of a computer-aided OSA detection scheme. Electrocardiogram (ECG) signals are widely used for computerized OSA detection. Again, the feasibility of a portable and wearable sleep quality monitoring devices necessitates the use of minimum number of leads. Therefore, automated OSA identification based on single-lead ECG is garnering the attention of sleep research community.

Various algorithms have been proposed in the literature for automatic OSA screening. Maier et al. [3] performed recurrence analysis on ECG signal to detect OSA events. Khandoker et al. [4] employed wavelet based features and feedforward neural network. Mendez et al. [5] explored both temporal features and spectral features extracted from power spectral densities of recurrence rate (RR) intervals and QRS area series and used a bivariate time-varying autoregressive model at each heart beat for OSA detection. KNN and neural networks were used to classify apneic data from normal data on a 1-min basis. Khandoker et al. [6] also used support vector machine (SVM) with 28 features extracted from heart rate variability (HRV) data and ECG-derived respiration data using wavelet decomposition to detect OSA. Yildiz et al. [7] utilized discrete wavelet transform (DWT), fast-Fourier transform (FFT) and least squares support vector machine (LS-SVM) for the automatic recognition of OSA from ECG signals. Bsoul et al. [8] implemented a real-time sleep apnea and hypopnea syndrome detection system using 111 features in both time and spectral domains extracted from ECG data. Xie et al. [9] extracted features from ECG and saturation of peripheral oxygen (SpO2) signals and employed classifier combination such as AdaBoost with Decision Stump and Bagging with REPTree. Varon et al. [10] used principal components of the QRS complexes as features and classified using least-squares support vector machine. Al-Angari et al. [11] heart rate variability, oxygen saturation, and respiratory effort signals to classify OSA events using support vector machine classifier. Chen et al. [12] propounded a single lead based scheme that utilizes an OSA severity index and support vector machine for OSA diagnosis. Nguyen et al. [13] employed heart rate complexity as measured by recurrence quantification analysis statistics of heart rate variability data to classify OSA events.

Fig. 1 gives a schematic outline of the automated sleep apnea identification algorithm proposed in this work. First, we segment the ECG signals in 1 min. basis. Various statistical and spectral features are then extracted from these signal segments. We then perform statistical analysis for feature selection. Classification of apnea and normal ECG signal segments are performed using Bagged decision trees. The efficacy of the selected features is demonstrated though intuitive, statistical and graphical analysis. Effect of various classifier parameters on algorithmic performance and the optimal choices of these parameters are also investigated. The proposed automated OSA screening algorithm is compared to previously published ones. Our experimental findings suggest that the OSA detection scheme propounded herein outperforms the state-of-the-art ones in accuracy, sensitivity and specificity.

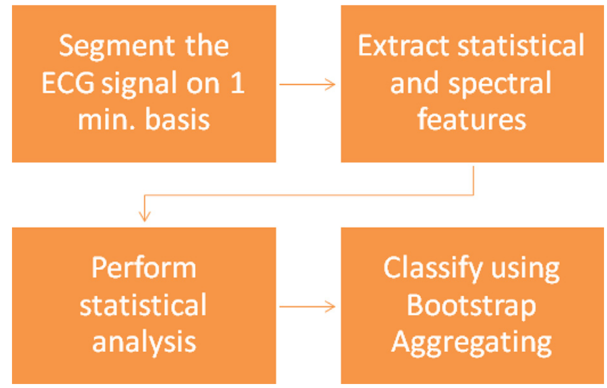

Fig. 1 – Schematic outline of the proposed OSA detection scheme.

The rest of the article is organized as follows. Section 2 describes the experimental data, elucidates our feature extraction, feature selection and classification scheme. We expound our experiments, optimal choice of parameters, the experimental results and the significance of these results in Section 3. Finally, Section 5 explicates how this work can be extended and concludes the article.

2. Materials and methods

2.1. *Experimental data description*

The experimental data used in this study can be accessed in Physionet's apnea-ecg Database [14]. A total of 35 subjects with OSA are used (classes a, b, c). Apnea Hypopnea Index (AHI) of these subjects ranges between 0 and 83. The age of those subjects is between 27 and 63 years (mean: 45 $\pm$ 10 years) with body mass index (BMI) between 19.2 and 45.33 kg m^2 (mean: 28.01 $\pm$ 6.49 kg m^2). Recordings vary in duration from slightly less than 7 h to nearly 10 h each. The records were labeled and scored by an expert for sleep apnea/hypopnea events on a 1-minute basis. Each record contains a set of reference annotations, one for each minute of the recording that indicates the presence or absence of apnea during that minute. ECG signals are sampled at 100 Hz with 12-bit resolution. Thus, the length of each 1-minute signal segment is 60 s or 6000 samples. Fig. 2 shows two such signal segments of the two classes- apnea and normal. More details on the data can be found in [14].

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