Simplified Process of Obstructive Sleep Apnea Detection Using ECG Signal Based Analysis with Data Flow Programming

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Abstract. The work is focused on detection of Obstructive Sleep apnea (OSA), a condition of cessation of breathing during night sleep caused by blockage of upper respiratory tract in an individual. ElectroCardioGram (ECG) signal is one of the clinically established procedures that can be relied on for deciding on the presence or absence of sleep apnea along with its severity in the subject at an earlier stage, so that the expert can advise for the relevant treatment. Earlier detection of OSA, can avoid the severe consequences leading to hypertension, Atrial-Fibrillation and day-time sleepiness that can affect the patient. ECG signal recordings from Apnea database from Physiobank, MIT website have been used for the purpose. The ECG signal based methods like QRS complex detection, RR interval variability, Respiratory Variability, Heart rate variability parameters used to detect OSA are compared and evaluated in order to select the most accurate method. Here we present the stepwise procedures, results and analysis of implementation methods used for detection of sleep apnea based on ECG signal using robust dataflow programming feature available in LabVIEW2014. Results indicate that accuracy, specificity and sensitivity of Heart Rate based detection method of OSA are 83%, 75% and 88% respectively and thus rated as one of the simple and reliable ways of detecting OSA.

Keywords: Sleep apnea · Obstructive Sleep Apnea · Apnea database · Physiobank · QRS complex detection · RR interval variability · Respiratory variability · Heart rate variability · Accuracy · Specificity and Sensitivity

1 Introduction

Sleep is an important activity essentially required for the human being to overcome the fatigue and rejuvenate the different physiological processes related to physical, emotional and psychological health. Sleep Apnea is defined as the undesired interrupted sleep behavior. In Sleep apnea conditions the affected person suffers from interruptions in sleep due to disordered breathing. As the breathing is stopped for a certain amount of time, oxygen level in the blood reduces. This is sensed by the Autonomic Nervous system (ANS) which commands the arteries supplying oxygen along with blood to constrict and increase the rate of flow of blood causing in turn higher blood pressure to suffice the demand. If this

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continues, the person ends up developing a high blood pressure even during day time. Atrial Fibrillation is also one of the commonly occurring problems for persons suffering from sleep apnea. Sleep-apnea is classified into three types Obstructive Sleep Apnea (SA), Central Sleep Apnea (CSA) and Mixed Sleep Apnea (MSA) as can be seen in Fig. 1. Obstructive Sleep Apnea is caused by the breathing disorder resulting in cessation of breathing completely or partially due to blockage of upper airway tract in spite of satisfactory respiratory effort. Obstructive sleep apnea indicates the complete blockage of upper airway, whereas Obstructive Sleep Hypo-apnea stands for partial blockage of upper airway. OSA affects adults normally in the middle age group. Central apnea caused by breathing disorder resulted out of lack or absence of respiratory effort from ANS. Among the different types of sleep apnea, Obstructive Sleep Apnea/Hypo-apnea are considered to be prevalent. We focus here on the study of OSA detection methods. The studies indicate that the patients suffering from OSA tend to have Atrial Fibrillation with a higher probability. If OSA is unattended, it contributes to hypertension causing heart related disorder. General symptoms of sleep apnea are excessive sleepiness, depression, impaired concentration, seen during day time where as the symptoms like nocturnal choking, heavy snoring sound, sweating and restless sleep behavior can be observed during night time. Early detection of OSA can help the affected person to get treated for his abnormal sleep behavior, which in turn can improve his health with the corrected sleep behavior. There is a lot of work done on Sleep apnea detection techniques proposed by researchers across the globe to find out a reliable and a cost effective way of detecting the OSA [1–3].

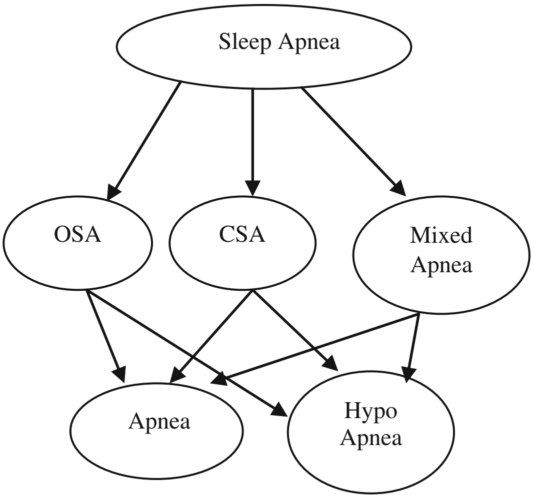

Fig. 1. Classification of types of Sleep Apnea

2 Survey of Sleep Apnea Detection Methods

There is a gold standard test called as Polysomnography (PSG) used for sleep studies which requires sophisticated and expensive laboratory setup. PSG test involves the procedures involving recording of sleep behavior of the subject for an overnight duration. The technique proves to be very cumbersome and inconvenient as the subject needs to undergo test in highly restricted conditions. Hence the need is to evolve an accurate, non-invasive and reliable alternative technique for sleep studies. There are several methods evolved over years and ECG signal is said to have emerged as one such option. As ECG signal has proven to be a standard, reliable test conducted through sophisticated equipments and commonly available facility in hospital setups, it is taken as an important diagnostic aid for many of the disease diagnostics. The ECG signal is modulated in its amplitude and frequency by breathing activity and thus carries relevant information about the respiration signal. This is due to the movement of ECG electrodes placed on chest caused by respiration action. ECG signal tapped from human being can be used to study the respiration signal hidden in it, using which we can infer on interrupted sleep effect due to respiratory disorder. Hence there is a need to analyze the variations in the parameters of the ECG signal caused by respiratory action, as well extract only the respiration information from the ECG signal. There are various signal processing and analysis methods employed to detect sleep apnea.

As per the literature survey, we could review the non-invasive methods based on ECG signal practiced for detection of Sleep Apnea. The popularly used signal processing methods are investigated and analyzed for respiration monitoring [1, 2]. The methods evolved to acquire respiration signal from single lead and multi-lead ECG signals are experimented. Clinical validation of the methods evolved to derive the respiration rate from the ECG derived Respiration signal and its estimation are discussed [3–5]. The popularly used signal processing techniques to extract ECG parameters like QRS complex are PanTompkins algorithm, Wavelet transform and Hilbert Transform techniques etc. [6, 7]. The initial activity of pre-processing the ECG signal can be done based on the different kinds of noise drastically affecting the quality of the acquired ECG signal [8–11]. One of the standard sources used by researchers for experimentation on various bio-signals across the world are from physiobank.org, having databases on ECG Arrhythmia, ECG-Apnea, EEG signals, EMG signals etc. In our proposed work, we have used databases on ECG Arrhythmia and ECG-Apnea, [12]. Further the data flow programming techniques used in LabVIEW2014 provide a robust set of built-in functions and tool kits that enable the researcher to test the algorithm in a much easier fashion and interpret the results in a very interactive way [13]. The standards are used by researchers to know the ideal ranges of ECG parameters in terms of amplitudes and time intervals, normal variants from the scientific statements released by Associations like American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society [14].

3 Plan and Implementation of Methodologies

The plan of implementation of the detection of Sleep Apnea can be realized using the various well established methods as presented in Fig. 2. ECG being a noninvasive technique has a large number of hidden parameters that help in detection of the respiratory behavior, in turn the presence and absence of Sleep Apnea. The first and the foremost step is to get the ECG signal either using data acquisition hardware like analog front end from the electrodes attached to human being or download bio-signal recordings from healthy subjects as well those with ailments. Next step is the preprocessing of ECG signal to eliminate the undesired noise from it, so that the pure ECG signal can be easily analyzed further for the accurate detection of sleep apnea. Preprocessing involves cascaded stages of filtering process involving a low pass filter (LPF) with cut off 150 Hz used to remove baseline wander noise, a high pass filter with cutoff 0.05 Hz to remove motion artifacts and finally a notch filter with cutoff 50 Hz to remove power line interference as shown in Fig. 3. Based on the strategies that can be employed for ECG signal analysis, the important are the QRS complex detection, ECG feature Extraction, Heart Rate Variability and ECG Derived Respiration (EDR) Signal extraction. For each of the strategies followed, the important signal processing methods used are the Pan Tompkins algorithm, under time domain approach and Fourier Transform, Wavelet Transform and Hilbert Transform based techniques under frequency domain approach. The first step common to all the methods is the QRS complex and ventricular beat detection followed by morphological and rhythm analysis [6–11]. The parameters analyzed under each method differ from each other.

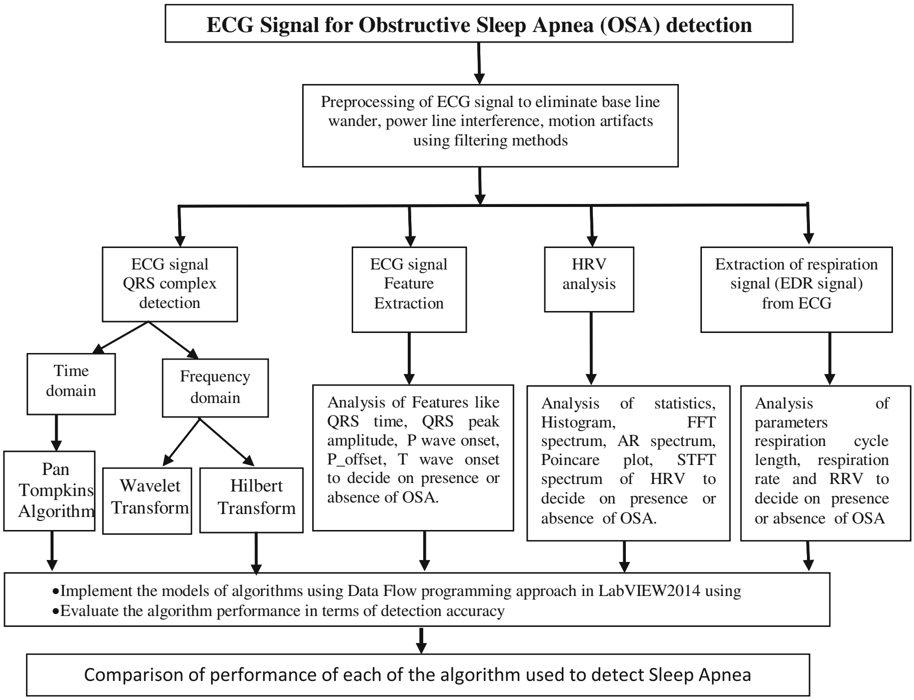

Fig. 2. Survey of ECG based OSA detection methods

Further the generic algorithm meant for sleep apnea detection involves the first step as preprocessing of ECG signal followed by the detection of QRS complex, its amplitude and location. Apart from that, even the ECG beat morphology features help the user get the ECG parameters accurately. Next is to detect the heart rate from the array of peaks

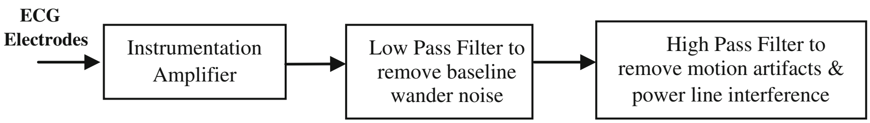

Fig. 3. Stepwise processes involved in data acquisition of ECG signal

and also the range of RR intervals. Mean heart rate provides the information to distinguish the normal case with that of apnea condition. But if there are repeated episodes of bradycardia and tachycardia condition, then it is the presence of sleep apnea. Based on the number of episodes of apnea it can be decided as mild OSA, moderate OSA, severe OSA or simply normal if the heart rate is well within the ideal range of heart beat between 60 to 70 bpm. The implementation of QRS complex detection, which can be implemented either using Pan-Tompkins algorithm as shown in Fig. 4 or using wavelet transformation technique as shown in Fig. 5. Amplitude and location of QRS complex is important to detect other parameters of ECG helpful in enhancing the accuracy of QRS detection. The collection of a set of parameters required to gather characteristics of ECG signal with respect to its respiration behavior.

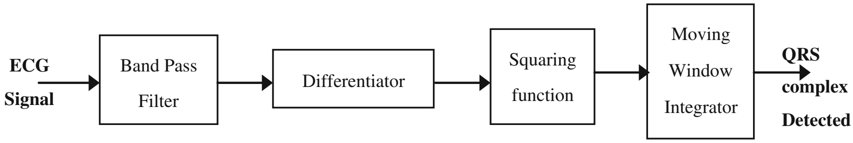

Fig. 4. Pan Tompkins algorithm for QRS complex detection

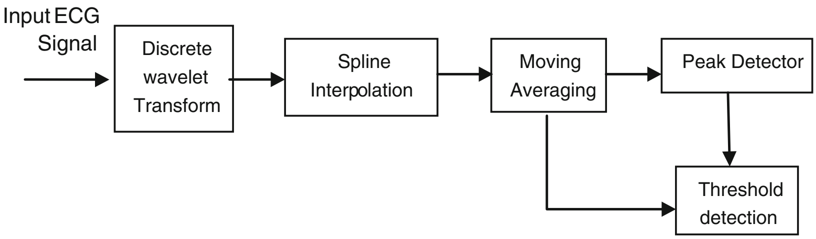

Fig. 5. Stepwise process of discrete wavelet transform method

The above discussed procedures are implemented using LabVIEW2014 from TI providing the robust environment for data flow programming providing user friendly built-in functions [13].

4 Implementation and Discussion of Results

The algorithms selected for ECG signal analysis as shown in Fig. 6 to detect sleep apnea are implemented using the Advanced Signal processing toolkit and Biomedical toolkit using LabVIEW2014. The below Fig. 7a shows the data acquision of ECG signal done in LabVIEW2014 using MIT ECG Apnea database and further of treatment of noise caused by artifacts, baseline wander and power line interference. Thus the purified ECG signal is now fed to the peak detector implemented using either using Wavelet transform or the Pan Tompkins algorithm. The stepwise procedure as shown in Fig. 8(a, b, c and d) is used to detect the QRS complex present in the signal and detect the set of peak amplitudes, its location and the time of occurrence can be thus used to compute the heart rate for every cycle. QRS peak detection process performed using wavelet transform technique is as shown in Fig. 9.

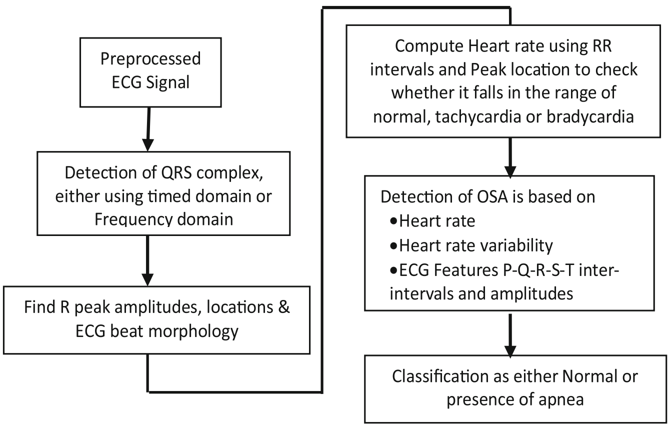

Fig. 6. Algorithm for detection of Sleep apnea based on ECG signal

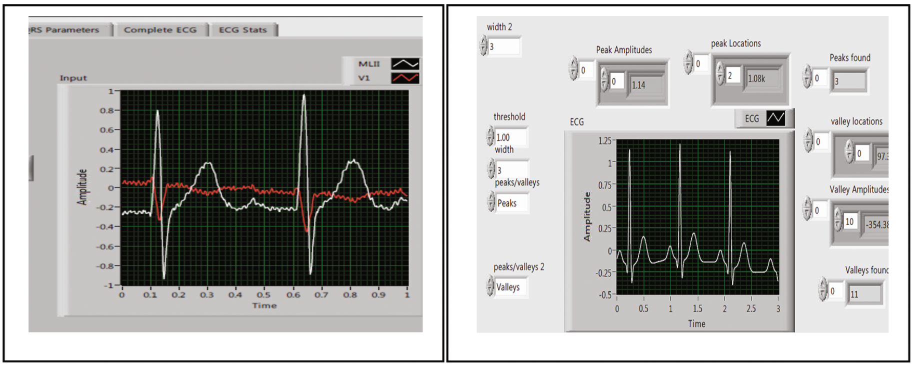

Fig. 7. (a) Reading the ECG signal with apnea (b) Identifying the peaks and valleys in the ECG signal input

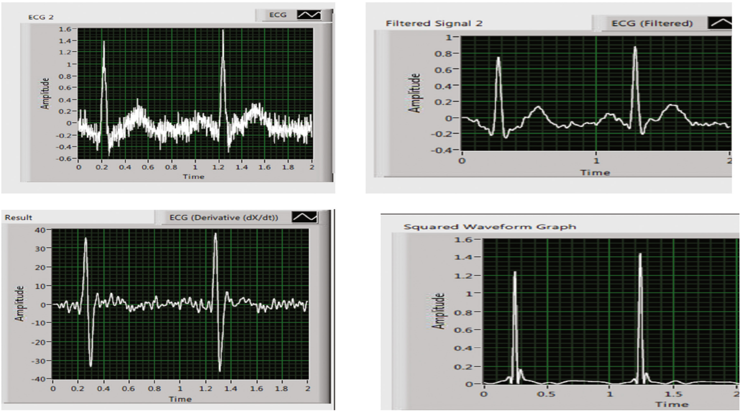

Fig. 8. Step wise procedure of identifying QRS complexes (a) Reading the ECG signal with apnea (b) Filtering to remove noise (c) Differentiation of the filtered output (d) Squaring the differentiated output to identify the peaks distinctly

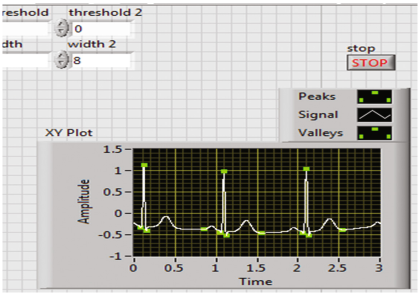

Fig. 9. Peaks and valleys detected by Wavelet transforms technique

No. of records	12
TP	7
TN	3
FP	1
FN	1
Accuracy	83%
Specificity	75%
Sensitivity	88%

Fig. 10. Performance measures of detection algorithm

Further the mean heart rate can be used to identify the slow heart rate, fast or normal heart rate, which is an important indicator of sleep apnea. One more observation is that the continuous episode of bradycardia followed by tachycardia is a case of sleep apnea. Thus the mean heart rate computed from the waveform measurements is done using the Feature extraction program. The algorithm for detection of apnea is based on the well defined ranges of ECG parameters for accurate classification. Thus the heart rate and HRV characteristics are used to determine the variation in RR intervals for the 12 sample records from ECG Apnea database and the detection process is summarized as shown in Fig. 9. The measures of performance of the algorithm are computed as 83% accuracy, 75% of specificity and 88% of sensitivity. We have used abbreviations for output status variables such as TP, TN, FP and FN in place of True Positive, True Negative, False Positive, and False Negative respectively. Here TP stands for the status, when the input ECG recording is judged by algorithm has significant number of apnea episodes, whereas TN stands for the input recording being judged as a normal one without any apnea episode, both matching with the expert opinion. FP and FN represents the algorithm output being contradicting the expert opinion in judging the status of the input ECG recordings wrongly. The performance measures of sleep apnea detection algorithm are computed using the formulae given below and are tabulated as in Fig. 10.

$$\text{Accuracy} = (\text{TN} + \text{TP})/(\text{Total no. of recordings})$$

$$\text{Specificity} = \text{TN}/(\text{TN} + \text{TP}) \ \& \ \text{Sensitivity} = \text{TP}/(\text{TP} + \text{FN})$$

5 Conclusion

Testing of algorithms can be effectively done through dataflow programming approach of LabVIEW2014, as it helps researchers to have interactive hands-on with signals, signal processing and analysis techniques. We could compare the advantages of using the best possible combination of QRS complex detection techniques, followed by signal analysis technique for basic heart rate based decision making algorithm. Further the results show that the algorithm can be improved by utilizing the ranges of values used for accurate classification using Fuzzy logic decision making.

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