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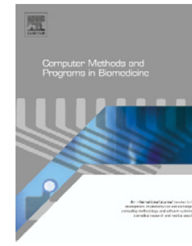

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Detection of apneic events from single channel nasal airflow using 2nd derivative method

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ABSTRACT

Detection of sleep apnea is one of the major tasks in sleep studies. Several methods, analyzing the various features of bio-signals, have been applied for automatic detection of sleep apnea, but it is still required to detect apneic events efficiently and robustly from a single nasal airflow signal under varying situations. This study introduces a new algorithm that analyzes the nasal airflow (NAF) for the detection of obstructive apneic events. It is based on mean magnitude of the second derivatives (MMSD) of NAF, which can detect respiration strength robustly under offset or baseline drift. Normal breathing epochs are extracted automatically by examining the stability of SaO_2 and NAF regularity for each subject. The standard MMSD and period of NAF, which are regarded as the values at the normal respiration level, are determined from the normal breathing epochs. In this study, 24 Polysomnography (PSG) recordings diagnosed as obstructive sleep apnea (OSA) syndrome were analyzed. By analyzing the mean performance of the algorithm in a training set consisting of three PSG recordings, apnea threshold is determined to be 13% of the normal MMSD of NAF. NAF signal was divided into 1-s segments for analysis. Each segment is compared with the apnea threshold and classified into apnea events if the segment is included in a group of apnea segments and the group satisfies the time limitation. The suggested algorithm was applied to a test set consisting of the other 21 PSG recordings. Performance of the algorithm was evaluated by comparing the results with the sleep specialist's manual scoring on the same record. The overall agreement rate between the two was 92.0% ($\kappa = 0.78$). Considering its simplicity and lower computational load, the suggested algorithm is found to be robust and useful. It is expected to assist sleep specialists to read PSG more quickly and will be useful for ambulatory monitoring of apneas using airflow signals.

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1. Introduction

Obstructive sleep apnea (OSA) is characterized by episodes of complete or partial pharyngeal obstruction during sleep [1]. Apnea is defined as the complete cessation of airflow for a minimum of 10 s during sleep. Hypopnea is commonly defined as a 30% or greater reduction in airflow associated with at least a 3–4% drop in oxygen saturation or an EEG alpha wave [1,2]. In the presence of apnea or hypopnea, there are increased efforts to breathe which lead to subsequent arousal and sleep fragmentation. The pathophysiologic changes associated with disrupted breathing are thought to be reasons for the symptoms and complications related to the OSA syndrome [3]. Medical complications associated with OSA syndrome include hypertension, diabetes mellitus, and cerebrovascular accidents [4]. Epidemiological studies estimate that 2–5% of the population meet the minimal diagnostic criteria of OSA syndrome [5].

Polysomnography (PSG) is the gold-standard method used for the assessment of sleep-disordered breathing (SDB). Standard diagnostic nocturnal PSG consists of evaluation of the following essential components: an electroencephalogram (EEG), an electro-oculogram (EOG), an electromyogram (EMG), nasal airflow (NAF), abdominal and thoracic movements, body position, a snore microphone, an electrocardiogram (ECG), and blood oxygen saturation (SaO_2). According to the SDB measurement technique, an episode of apnea is detected in the nasal and oral airflow channels by checking its amplitude, while an arousal is detected with EEG and evidence of SaO_2 desaturation [6]. Manual scoring of apneic episodes from a one night PSG is very laborious and time-consuming. Furthermore, the analysis is subject to potential errors and inconsistencies related to the rater's subjectivity and fatigue, as presented in several studies of inter-scorer variability [7].

Efforts to overcome some of the problems associated with manual scoring have led to the introduction of computerized and computer-assisted SDB detection systems. This study focused on apnea detection as a primary means of automated SDB detection system because apnea is well defined and frequently found in patients with OSA syndrome. Various methods have been applied in apnea detection by analyzing several bio-signals, such as ECG [8,9], respiratory patterns [10], oxygen saturation [11–13], and acoustical respiratory impedance [14]. Some studies have been performed to overcome the inconvenience of PSG, while other studies have investigated means to raise the performance of detection. Clinically, NAF is the most direct method of determining apnea. However, commercial PSG programs rarely provide the automatic detection of apneic events, which are currently still being marked from PSG recordings manually by the sleep specialist. NAF is commonly measured by a thermistor or thermocouple which is susceptible to offset and baseline drift. Therefore, checking amplitude by itself can generate the incorrect detection results. In this paper, we present a new alternative algorithm for apnea detection based on the analysis of NAF signals. By estimating the normal breathing from SaO_2 and NAF, a standard for respiration strength can be determined. The second derivative of NAF can remove the drift and offset contained in NAF [15]. This study evaluated the performance of the presented algorithm by comparing its results against those of the sleep specialist's manual scorings.

Table 1 – The statistics of the PSG recordings of 24 patients

Variables	Mean	S.D.
Age [years]	50.2	11.1
TIB[a] [min]	483.9	28.5
SL[b] [min]	6.5	5.5
TST[c] [min]	398.7	52.0
SE[d]	0.8	0.1
RDI[e] [1/h]	48.0	19.4
AI[f] [1/h]	37.7	20.5

[a] TIB: time in bed (total time in which a patient spend in bed).
[b] SL: sleep latency.
[c] TST: total sleep time.
[d] SE: sleep efficiency (obtained by diving TST by TIB).
[e] RDI: respiratory disturbance index (numbers of apneas and hypopneas per hour).
[f] AI: apnea index (numbers of apneas per hour).

2. Methods

2.1. Subjects

We analyzed the PSG recordings from subjects diagnosed with OSA at the Center for Sleep and Chronobiology of Seoul National University Hospital in Korea. At this center, more than 500 PSGs are conducted annually. One of four registered polysomnographic technologists (RPSGT) initially scored the PSG, identifying sleep stages and significant sleep events. A board certified sleep medicine physician made the final review of the PSG. In order to minimize the intra-rater variability, we selected the PSG recordings conducted within a 1-year period, from November 2004 to November 2005. All subjects were men with a mean age of 50.2 ± 11.1 years and no known co-existing medical or psychiatric diseases. Subjects with a respiration disorder index (RDI) <10/h were excluded from the study. Sleep recordings from 24 subjects which satisfied inclusionary criteria were selected. Sleep- and apnea-related parameters of the recordings are summarized in Table 1.

2.2. *Theoretical bases of derivative analysis in detection of apnea*

2.2.1. *Mean magnitude of the second derivatives (MMSD) of NAF*

In consideration of the periodicity of the NAF signal, we simulated a respiration signal as a sinusoidal signal with offset and drift.

$$\text{Simulated NAF measurement} = C_1 \sin(at) + C_2 \sin(bt) + C_3 \text{ where } a \gg b \quad (1)$$

$$\text{1st derivative of NAF signal} = aC_1 \cos(at) + bC_2 \cos(bt) \quad (2)$$

$$\text{2nd derivative of NAF signal} = -a^2C_1 \sin(at) - b^2C_2 \sin(bt) \quad (3)$$