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Technical note

Screening of obstructive sleep apnea with empirical mode decomposition of pulse oximetry

Gastón Schlotthauer[a,b,*], Leandro E. Di Persia[c,b], Luis D. Larrateguy[d], Diego H. Milone[c,b]

[a] Lab. of Signals and Nonlinear Dynamics, Facultad de Ingeniería, Universidad Nacional de Entre Ríos, Argentina
[b] National Council of Scientific and Technical Research (CONICET), Argentina
[c] Research Center for Signals, Systems and Computational Intelligence (sinc(i)), Facultad de Ingeniería y Ciencias Hídricas, Universidad Nacional del Litoral, Argentina
[d] Centro de Medicina Respiratoria, Paraná, Argentina

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ABSTRACT

Detection of desaturations on the pulse oximetry signal is of great importance for the diagnosis of sleep apneas. Using the counting of desaturations, an index can be built to help in the diagnosis of severe cases of obstructive sleep apnea–hypopnea syndrome. It is important to have automatic detection methods that allows the screening for this syndrome, reducing the need of the expensive polysomnography based studies. In this paper a novel recognition method based on the empirical mode decomposition of the pulse oximetry signal is proposed. The desaturations produce a very specific wave pattern that is extracted in the modes of the decomposition. Using this information, a detector based on properly selected thresholds and a set of simple rules is built. The oxygen desaturation index constructed from these detections produces a detector for obstructive sleep apnea–hypopnea syndrome with high sensitivity (0.838) and specificity (0.855) and yields better results than standard desaturation detection approaches.

1. Introduction

Sleep disorders include more than 80 frequent pathologies in adults and children [1]. Such disorders cause daytime sleepiness, affecting between 35 and 40% of the adult population of USA, and are an important cause of morbidity and mortality. As a result of this high prevalence, severe complications, and concomitant diseases in the non treated cases, there are very important associated costs [2]. The more common and important sleep pathology is the obstructive sleep apnea–hypopnea syndrome (OSAHS). This disorder is characterized by repetitive airflow reduction caused by an intermittent partial or complete upper airway obstruction during sleep. The main consequences of this disorder are sleep fragmentation, reduced blood oxygen saturation, and excessive daytime somnolence [3–6]. According to recent studies [7,8], the prevalence of OSAHS in a general population, without taking into account symptoms of sleepiness, has been estimated to be 24% in a males and, when associated with these symptoms, it decreases to approximately 3–7% in men and 2–5% in women. It is worth to be mentioned that it is much higher, e.g. ≥50%, in patients with cardiac or metabolic disorders than in the general population.

The current gold standard for the diagnosis of OSAHS is polysomnography (PSG). PSG is an overnight study made at a sleep center, in a quiet and dark room, that consists of simultaneous recording of electroencephalography (EEG), electrooculography (EOG), electromyography (EMG), electrocardiography (ECG), oxygen saturation (SpO_2), oronasal airflow, thoracic and abdominal movement, body position, and other signals. PSG allows to estimate the apnea/hypopnea index (AHI) that is used as the primary index of OSAHS severity. PSG is supervised by a technician, and its analysis requires a tedious scoring, often by hand [9]. This study is cost intensive, its availability is limited, and only one study can be made per night.

As alternatives to PSG, several approaches have been proposed using cardiac, respiratory, and snore sounds [10,11], pulse oximetry [3], ECG [12], nasal airway pressure [4,13] and combinations of several signals [14]. These signals were studied by time-frequency analysis techniques [15], statistical approaches based on several *ad hoc* indexes [14], empirical mode decomposition [4,13], information theory [3], linear and quadratic discriminants [10], and other methods. Unlike other signals for which the recording instrumentation is more complex, nocturnal pulse oximetry is a low-cost technique and it can be easily applied in outpatient studies with the purpose of screening of OSAHS. However, pulse oximetry requires

* Corresponding author at: Lab. of Signals and Nonlinear Dynamics, Facultad de Ingeniería, Universidad Nacional de Entre Ríos, Argentina. Tel.: +54 3434975100.
E-mail address: gschlotthauer@conicet.gov.ar (G. Schlotthauer).

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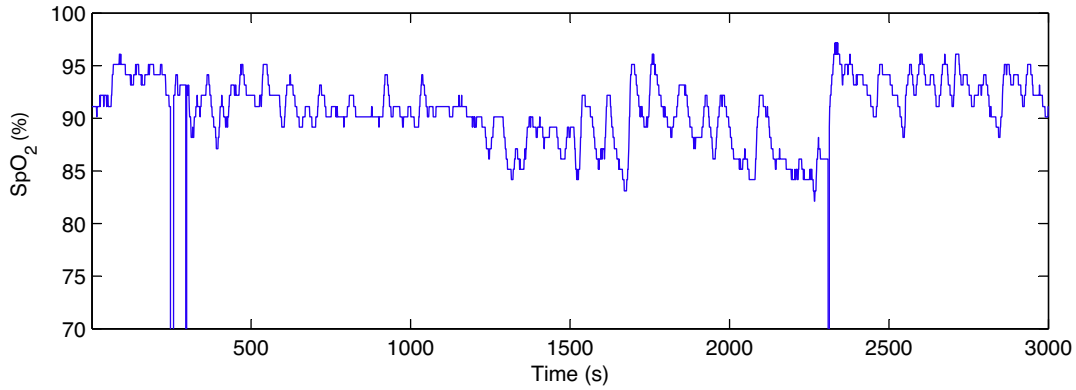

Fig. 1. Typical SpO_2 signal from a patient suffering OSAHS.

more sophisticated processing tools to extract relevant information.

Empirical mode decomposition (EMD) is a complete data-driven signal analysis technique, that can be applied to nonstationary and nonlinear signals, proposed by Huang et al. [22].[1] EMD decomposes a signal into a usually small number of components known as Intrinsic Mode Functions (IMF) or modes. EMD was successfully used for the extraction of the respiratory signal from ECG [23], and for detecting apneas processing the nasal airflow signal [4] and even the ECG [24]. As an undesired effect, we can mention the problem known as "mode mixing", where very similar oscillations are present in different modes. This is partially alleviated with noise-assisted EMD versions, as the Ensemble EMD [25] with very good results in voice processing [26], but with high computational cost and a residual noise in the reconstructed signal. More recent noise assisted versions overcome some of these problems [27,28].

In this work, we present an algorithm based on EMD for detecting desaturations associated with sleep apnea/hypopnea in pulse oximetry signals. The purpose of this procedure is to estimate an index that behaves in a similar way than the classical Apnea/Hypopnea Index derived from PSG, but using only information from oxygen desaturations measured by pulse oximetry. This will be done by decomposing the oximetry signal using EMD, identifying the particular modes where the information associated to desaturations appears more clearly, and using a set of properly chosen thresholds and simple rules to count each desaturation.

2. Materials

2.1. Oximetry signal

2.1.1. SpO_2 signal basis

Oximetry is the measurement of the percent saturation of oxygen in hemoglobin. The arterial oxygen saturation is commonly referred as SaO_2. Pulse oximetry is a noninvasive estimation of the peripheral oxygen saturation (SpO_2) based on the transmission, absorption, and dispersion of light as it passes through hemoglobin. The reading is obtained using a light sensor containing two sources of light (red and infrared) that are absorbed by hemoglobin and transmitted through tissues to a photodetector. Measurement of SpO_2 is less accurate at low values, and 70% saturation is generally taken as the lowest accurate reading. Typical technical specifications of pulse oximeters include a sampling rate of 1 Hz, a resolution of 1%, and an accuracy of ±2% in the range of 70% to 100%.

In Fig. 1 a SpO_2 signal corresponding to a patient suffering OSAHS is shown. The range was limited to 70– 100 %. Several characteristics of this signal are illustrated in this example. Typical disconnection errors are at 250, 300, and 2300 s (the value provided by the oximeter in these events is 0.1%). Examples of desaturation events can be observed at 1000 s and between 2000 and 3500 s, where sawtooth-like waveforms are present. Additionally, a low frequency tendency can be noticed in the segment shown.

2.1.2. SpO_2 and OSAHS

A full PSG is required for the diagnosis of OSAHS. With these records, a specialized physician can accurately diagnose this syndrome, taking into account the number of complete and partial obstructions (apnea and hypopnea respectively) of breathing per hour of sleep. This quantity is known as the Apnea–Hypopnea Index (AHI) [29]. It is a very expensive study and the sleep laboratories are scarce, specially in developing countries.

The nocturnal transcutaneous pulse oximetry is used with increasing frequency for early screenings of OSAHS due to its low cost and simplicity. During obstructive apneas, oxygen desaturations are common, but they can be absent with hypopneas or in events with increased upper airway resistance [29]. In the first case, the desaturations show a typical sawtooth waveform with a rapid increase in SpO_2 during or after the arousal. However, this increase is not as abrupt in hypopneas and the sawtooth pattern can be completely missing in central apneas.

An obstructive apnea/hypopnea event is characterized by a transient reduction or complete cessation of breathing. In the clinical practice apneas are not considered differently from obstructive hypopneas because these events have similar pathophysiology. To be considered as an apnea/hypopnea event, criterion 1 or 2, plus criterion 3 of the following must be fulfilled [30]:

1 The amplitude of a valid signal related to the breathing must present a clear decrease (≥50%) from its baseline. This baseline is defined as the mean amplitude of the signal in stable breathing and oxygenation in the 2 min preceding the onset of the event.
2 A clear reduction in the amplitude of a validated measure of breathing during sleep that does not reach the previous criterion, but occurs with an oxygen desaturation greater or equal to 3% or an arousal.
3 The duration of the event is 10 s or longer.

In this work, we are focused in detecting the blood oxygen desaturations, with the intention of identify events associated with criteria 2 and 3. Our interest lies in estimating an index with high sensitivity for OSAHS detection. However, as could be seen in Fig. 1,

[1] Details about EMD can be found in the Supplementary Material accompanying this paper.