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A mixture of experts for classifying sleep apneas

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ABSTRACT

This paper presents a novel approach for classifying sleep apneas into one of the three basic types: obstructive, central and mixed. The goal is to overcome the problems encountered in previous work and improve classification accuracy. The proposed model uses a new classification approach based on the characteristics that each type of apnea presents in different segments of the signal. The model is based on the error correcting output code and it is formed by a combination of artificial neural networks experts where their inputs are the coefficients obtained by a discrete wavelet decomposition applied to the raw samples of the apnea in the thoracic effort signal. The input coefficients received for each network were determined by a feature selection method (support vector machine recursive feature elimination). In order to train and test the systems, 120 events from six different patients were used. The true error rate was estimated using a 10-fold cross validation. The results presented in this work were averaged over 10 different simulations and a multiple comparison procedure was used for model selection. The mean test accuracy obtained was 90.27% ± 0.79, and the values for each class apnea were 94.62% (obstructive), 95.47% (central) and 90.45% (mixed). Up to the authors' knowledge, the proposed classifier surpasses all previous results.

1. Introduction

There are more than 90 different sleep disorders but sleep apnea–hypopnea syndrome (SAHS) is one of the most common among them. SAHS is characterized by the occurrence of 5 or more breathing pauses (whether apnea or hypopnea) per hour of sleep. An apnea is defined as a pause in breathing, or cessation of the airflow in the respiratory tracts, of at least 10 s in duration. The event is defined as a hypopnea when, rather than a complete cessation, a considerable reduction occurs in the airflow accompanied by a desaturation of oxygen levels in arterial blood (American Academy of Sleep Medicine, 2005).

These breathing pauses cause continual interruptions of sleep and, as a consequence, diurnal somnolence, memory loss, a reduced capacity to concentrate and a general deterioration in intellectual capacity. Furthermore, there is a proven increase in mortality due principally to cardiovascular complications and traffic accidents (Harding, 2000). These facts have converted sleep study into a scientific discipline in itself and a relatively new medical speciality (Sociedad Española de Neumología y Cirugía Torácica, 1993).

A diagnosis of SAHS is made on the basis of the analysis of a polysomnogram (Sociedad Española de Neumología y Cirugía Torácica, 1993), defined as a continuous and simultaneous recording of a set of variables described as follows: electroencephalogram, electrooculogram, electromyogram, airflow in the upper air tracts, oxygen saturation in arterial blood (SaO_2) and respiratory effort (both abdominal and thoracic).

Typically, the diagnostic process comprises, as a first step, the detection of possible apneic events over the airflow signal by searching a cessation or reduction of the air flow during sleep lasting at least 10 s or more. Once the apneic events are detected they have to be confirmed using other signals of the polysomnographic record. Fig. 1 shows an example of detection of apneic events. Then, the confirmed apneic events will be classified over the corresponding segment of the thoracic effort signal. For classification purposes, three basic types of respiratory disfunctions are distinguished:

- Obstructive apnea: This is the more frequent pattern, characterized by the presence of thoracic effort for continuing breathing (see Fig. 2(a)).
- Central apnea: This is characterized by a complete cessation of respiratory movements (see Fig. 2(b)).
- Mixed apnea: This pattern is a combination of the previous two, defined by a central respiratory pause followed, in a relatively short interval of time, by an obstructive ventilatory effort (see Fig. 2(c)).

In the diagnosis, the prevalence of a particular type of apneic event determines the type of the syndrome of the patient:

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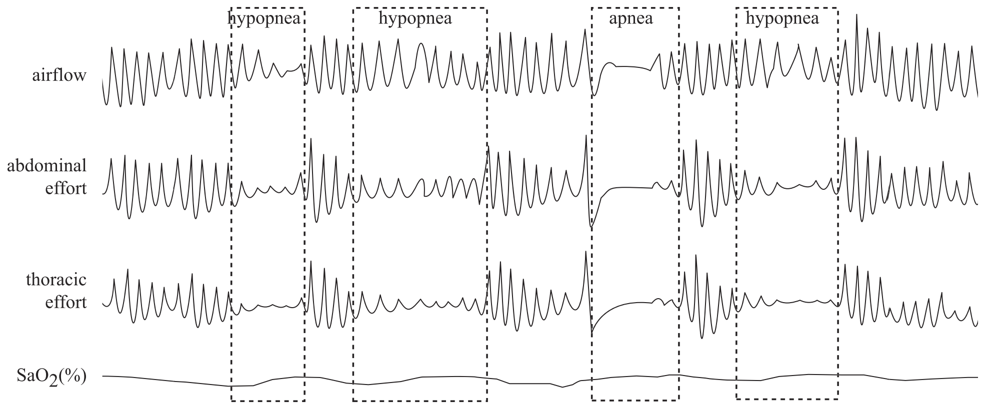
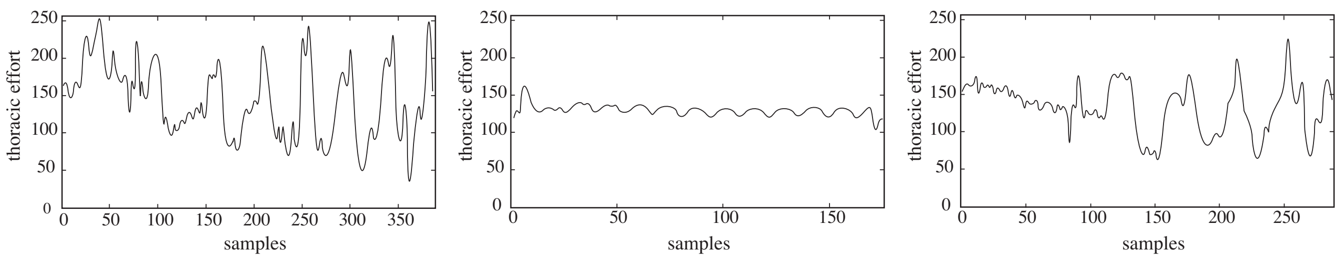


Fig. 1. A selection of signals of a polysomnographic record. The apneic events appear marked.



(a) Obstructive (b) Central (c) Mixed

Fig. 2. Example for the three types of sleep apnea of the behavior of the thoracic effort signal segment corresponding to apneic event.

obstructive SAHS (OSAHS), when most of the events are obstructive; or central SAHS (CSAHS), when the large majority of events are the central ones. Mixed events rarely appear isolated, but rather are usually accompanied by central and obstructive events. The diagnosis offered for a patient who presents mixed events will be OSAHS when there is a predominance of obstructive events, or CSAHS if central events are the predominant ones (Thorpy, 1990). From a clinical point of view, it is important to be able to distinguish correctly between obstructive apneas and central apneas, because once the syndrome is diagnosed its classification is important for the prescription of an appropriate therapy (Steltner et al., 2002).

For the diagnosis of SAHS, the clinician needs to review the polysomnographic recording manually. This supposes a high cost in a double sense: in time, for the length of the record of a night of sleep which can easily surpass 500 m of printout; and in work, for the multitude of signals involved in the analysis and their complexity. For this reason, computational systems are almost indispensable in order to facilitate the evaluation process of these polysomnographic records. Thus, many companies and medical laboratories have created new systems capable of making the classification of sleep phases, the detection of respiratory events during sleep or even both. Nevertheless, these systems present several deficiencies (Hernández-Pereira, 2000). To surpass these shortcomings other approaches have appeared in the academic field (Lu, Zhang, & Zhang, 2005; Senny, Destine, & Poirrier, 2008; Zemen, Clabian, & Pfutzner, 1998).

Our contribution in the area of automatic diagnosis of SAHS is the intelligent monitoring system SAMOA (Cabrero-Canosa et al., 2003; Cabrero-Canosa, Hernández-Pereira, & Moret-Bonillo, 2004). SAMOA is a computerized system for respiratory analysis and sleep study, which makes a particularized diagnosis of the patient with respect to the possible existence of SAHS. In order to make the diagnosis, first, and as shown in Fig. 3, a detection module receives the airflow signal and returns the location of each apnea. Subsequently, a sample selector module extracts the corresponding samples of the apneas in the thoracic effort signal. Afterwards, a pre-processing module receives these raw samples and extracts the features that will serve as inputs to the classification module that will label the detected apnea as central, obstructive or mixed.

The classification of apneas is a complex task and several different approaches have been tried for the SAMOA system in order to adequately classify the different apneic events detected. In Cabrero-Canosa et al. (2003) a rule-based system was employed but only a 78.71% of accuracy was obtained. The set of inputs was composed by features extracted from the respiratory effort signal (e.g. area under the signal, baseline...) together with the patient's weight and height. In a later work (Hernández-Pereira, Carrillo-Rozas, Cabrero-Canosa, & Moret-Bonillo, 2002), an artificial neural network (ANN), specifically a multilayer perceptron, was employed using as inputs the raw samples extracted from the thoracic effort signal segment corresponding to an apnea. With this approach, a global accuracy of only 75.32% was obtained. Currently, the classification module included in SAMOA is also based on an ANN but its input is now formed by the coefficients of a discrete wavelet decomposition applied to the raw samples of the apnea in the thoracic effort signal. With this new approach the global accuracy was improved up to a 83.78%. However, one of the features of this classifier is that it requires a balanced training set (i.e. all classes being equally represented) in order to obtain good accuracy. On the other hand, when talking about apneic events, the prevalence of obstructive apneas is much higher than that of the other two classes, with the class of mixed apnea being the most difficult to obtain examples. For this reason, a large number of examples that could be very useful for training have to be discarded in order to build a balanced