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Technical note

Automatic detection of drowsiness in EEG records based on multimodal analysis

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ABSTRACT

Drowsiness is one of the main causal factors in many traffic accidents due to the clear decline in the attention and recognition of danger drivers, diminishing vehicle-handling abilities. The aim of this research is to develop an automatic method to detect the drowsiness stage in EEG records using time, spectral and wavelet analysis. A total of 19 features were computed from only one EEG channel to differentiate the alertness and drowsiness stages. After a selection process based on lambda of Wilks criterion, 7 parameters were chosen to feed a Neural Network classifier. Eighteen EEG records were analyzed. The method gets 87.4% and 83.6% of alertness and drowsiness correct detections rates, respectively. The results obtained indicate that the parameters can differentiate both stages. The features are easy to calculate and can be obtained in real time. Those variables could be used in an automatic drowsiness detection system in vehicles, thereby decreasing the rate of accidents caused by sleepiness of the driver.

1. Introduction

The ability of a person to remain alert and make decisions quickly decreases considerably during the drowsiness stage. This situation presents a potentially problem in drivers. The National Highway Traffic Safety Administration estimates that between 56,000 and 100,000 crashes are the direct results of drowsiness resulting in more than 1500 fatalities and 71,000 injuries annually [1]. Likewise, it produced economic losses of 230 billion dollars according to Federal Highway Administration, Office of Safety Integration [2]. With the ever-growing traffic conditions this problem will further increase. So it is important to characterize the drowsiness and to develop automatic detectors of this stage, in order to avoid and reduce the drastic number of crashes and traffic accidents caused for this reason.

Reliable detection of drowsiness is one of the leading objectives in the development of new Advanced Driver Assistance systems. Some of the automatic detection methods are based on studying the driver behavior and the driving performance [3,4]. However, their parameters easily vary according to different vehicle types and driving conditions. Other research groups have proposed techniques based on head and eye movement [5,6], using a camera to acquire the images. Monitoring is good but difficult to commercially promote since nearly all drivers dislike being monitored with a camera directly focusing on their bodies all the time [3]. There are also methods that employ biomedical signal processing to detect drowsiness [7–13] found in related literature.

Biomedical signals are especially useful to collect information from the body's response during the drowsiness cycle. Some authors use the electrocardiographic [11] or electro-oculographic signals [12]. Electroencephalography (EEG) is the most-widely used technique to measure the electrical activity of the brain [14], and is the standard technique in sleep studies. Several authors have proposed the analysis of EEG to identify the Drowsiness Stage (*DS*) [7–10]. The disadvantage of techniques based on biomedical signals is that they require sensors and cables on the body, but it could be easily solved by placing new wireless sensors in a non-intrusive system [13].

Brain electric activity shows characteristic wave patterns in some states, and their differences between being awake and asleep have been studied intensively [15,16]. Different EEG signal processing techniques have been used to identify *DS*. In Papadelis et al. [9], the relative bands ratio (RBR) of EEG and different types of entropies were using 8 EEG and several EOG, EMG and ECG channels. Nikhil and co-workers [17] found that the power spectrum of Alpha band in the EEG is correlated with the lost of alertness in drivers. In the experiment they used 34 EEG/EOG/ECG electrodes. Researchers like Makeig et al. [18] and Jung et al. [19] have also implemented the spectral analysis of EEG records using 33 and 2 channels of EOG, respectively. Most of the aforementioned techniques involve complex mathematical processes, or require a large

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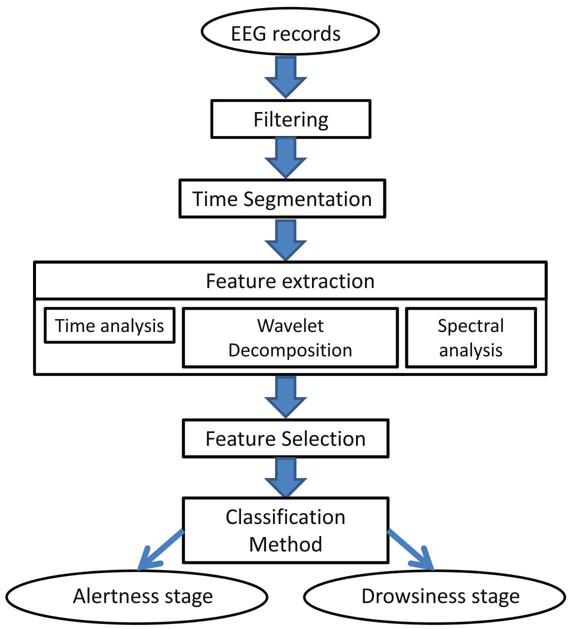

Fig. 1. Block diagram of the algorithm.

number of EEG channels, which are unpleasant for the driver. Picot et al. [20], proposed a technique with one EEG channel, based on means comparison test of the relative bands of EEG. The advantage of this method is the comfort of the driver because of the lower number of electrodes needed for feature computation. In recent work by Lin et al. [13], wireless EEG-Based interfaces have been proposed for a drowsiness detection system. In a previous work, Lin and co-workers [21] combined ICA, power-spectrum analysis and fuzzy neural network to estimate the Alertness Stages (*AS*) of the drivers.

The aim of this work is to develop an automatic method to detect the *DS* in EEG records using time, spectral and wavelet analysis. In order to differentiate *DS* from *AS*, a total of 19 features computed in only one EEG channel were analyzed. After a selection process 7 parameters were chosen and fed to a classifier based on neural networks (NN). We proposed the hypothesis that the brain patterns associated to drowsiness can be detected using only one EEG channel. In this sense, the results of a preliminary study showed promising evidence [22].

2. Materials

The EEG records of 16 subjects from the MIT-BIH Polysomnographic Database[1] were used [23]. All the patients are male and range between 32 and 56 years in age (average 43 years old). The channels used in the database are C3-O1, C4-A1 and O2-A1 on the 10–20 montage system. The sampling frequency is 250 Hz. The sleep stages are scored by experts, according to the Rechtschaffen and Kales criteria [24]. The epochs labeled as "Awake stage" and "Stage I" (S1) have been used in this work. Those epochs corresponds to *AS* and *DS*, respectively [25]. In the literature, fatigue, sleepiness and drowsiness, are often used synonymously [26].

3. Methods

Fig. 1 shows the block diagram of the proposed algorithm. The process begins with the filtering of the brain rhythm followed by the time segmentation stage. Next the feature extraction section includes the wavelet decomposition, the time and the spectral analysis. The feature selection step is performed using *Linear Discriminant Analysis* (LDA). In the last section the classification of *AS* and *DS* is carried out.

[1] Circulation Electronic Pages: http://circ.ahajournals.org/cgi/content/full/101/23/e215.

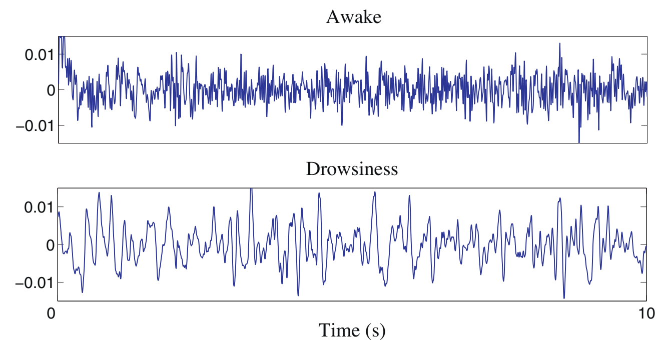

Fig. 2. Alertness and drowsiness 10 s EEG segments taken between C3 and O1. Patient #48.

3.1. Filtering

The signals were filtered with a 2nd order, bidirectional, Butterworth, band-pass filter with cut-off frequencies of 0.5–60 Hz. Then the biological noise and line interferences were removed from the records with a cascade of adaptive filters [27]. These filters could be implemented in a real car driving situation and the different stages of the cascade would be feed on line with the actual artifacts present in a car, like biological signal of the driver or electrical interferences of the vehicle.

3.2. Time segmentation

The 5 s segmentation of the EEG was done for the further analysis, according to the results of a previous work [22]. This process assures statistical stationary needed for the estimation of the Power Spectral Density (PSD).

3.3. Feature extraction

The activity of the brain is divided into frequency bands, named: Delta (0.5–4 Hz), Theta (4–8 Hz), Alpha (8–12 Hz), Beta (12–30 Hz) and Gamma (over 30 Hz), [28]. In this paper, there have been obtain 19 features from time and spectral analysis and wavelet decomposition of the EEG signal.

3.3.1. Time analysis

In time domain, the following parameters were calculated: Maximum (Max), Minimum (Min) and Standard Deviation (STD) values of the signal.

3.3.2. Spectral analysis

Fig. 2 shows an example of *AS* and *DS* in 10 s EEG segment. The *AS* has higher frequency components than the *DS*, so it is important to analyze the spectrum of each one.

The mean value of each segment was removed, and then the PSD of each segment was estimated with the Burg method. An order of 20 was chosen for Burg method, (based on a previous work [22]). The 10 features extracted from the PSD are: Central Frequency (CF), Peak frequency (PF), Ratio H/L, (RH/L), First and Third Quartile Frequency (Q1F and Q3F), Spectral Standard Deviation (SSD), Interquartile Range (IR), Maximum Frequency (MaxF), Asymmetry Coefficient, (AC) and Kurtosis Coefficient (KC).