Automatic EOG analysis: A first step toward automatic drowsiness scoring during wake-sleep transitions

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EEG und EOG Analyse: Ein erster Schritt zu einer automatischen Schlafanalyse

Zusammenfassung Es werden Algorithmen präsentiert, die Muster im EEG und EOG identifizieren, um Schlafigkeit am aktiven Individuum zu erkennen. Dazu müssen im EEG Alpha- und Thetawellen, sowie im EOG Augenblinks erkannt werden.


Die Auswertungen der EEG Analyse zeigten, dass sich die gesuchten EEG Frequenzbänder nicht gut identifizieren lassen. In der Diskussion zeigen wir, dass eine globale Analyse der Zeit-Frequenz-Verteilung des EEGs eine bessere Erkennung von Alpha- und Thetawellen ergeben sollte.

Schlüsselwörter EEG – EOG – Schlafigkeitserkennung – Blink Erkennung – Hilbert Huang Transformation – Karolinska Schlafigkeitsskala

Summary The first developments for processing electrooculogram (EOG) signals in order to automatically score the drowsiness level of an active subject are presented. Such a tool will be used to validate drowsiness detection systems based on behavioural measurements. In addition, preliminary work on automatic drowsiness scoring by utilizing the Karolinska Drowsiness Score (KDS) is presented at the end of the paper.

The originality of this blink detection algorithm is the analysis of EOG velocity based on expert rules. Our tool is applied to about 30 hours of EOGs and resulting blinks are compared with the blinks determined by visual analysis. More than 97.7 % of blinks are detected and less than 0.2 % of detected blinks are eye movements, except in two particular cases.

Key words electrooculogram – automatic blink detection – drowsiness detection – Karolinska Drowsiness score
Introduction

The work presented here is a part of the activity A.4.4.1: Criteria for sleep and stress detection and data feature extraction algorithms; of the FP6 Integrated Project SENSATION (Advanced Sensor Development for Attention, Stress, Vigilance & Sleep/Wake-fullness Monitoring). The aim of this activity is define criteria for detection of drowsiness and stress and to propose algorithms for extracting features from behavioural (e.g. body, head and eyelid position) or physiological signals, (e.g. electrooculogram (EOG) or electroencephalogram (EEG)). The features of the behavioural signals will be input from drowsiness prediction systems that are developed in other activities of the project. On the other hand, the features of the physiological signals will be used to validate these systems. Indeed, EOG and EEG are commonly used to estimate drowsiness levels or sleep stage [3, 5, 9–11], whereas many papers [1, 2, 4, 6–8, 12], propose various physiological signals processing developments to automatically generate sleep stages. However, only one reference [2] deals with drowsiness and proposed a tool to help experts during the visual analysis of the EOG. So far, visual analysis of EOG and EEG is used by physiologists to quantify drowsiness. Such an analysis is tedious and time-consuming when a large quantity of data have to be processed. The ultimate goal of the work presented in this paper is the automatization of such an analysis; however this paper focuses on automatic blink detection in EOGs.

The drowsiness scale selected for the activity A.4.4.1 is the Karolinska Drowsiness Score (KDS). This method, proposed by Åkerstedt’s group at the Karolinska Institute, consists of values ranging from 0 % to 100 %, in steps of 10 %. Two KDS have been proposed: one is based on EOG features only, the other one on both EEG and EOG characteristics. In both cases the signals are analysed in 20-second epochs, which are divided into 10 sub-intervals. If signs of drowsiness, i.e. long blinks or small-amplitude blinks when only EOG is considered, are detected in X sub-intervals, then the KDS is set to X*10 %. According to this definition, the computation of the drowsiness levels first requires the identification of the blinks. The algorithm that we developed for this task is presented in the following section.

Methods

The signals shown in this section and used to adjust the threshold values presented below come from the Pilot 2.5 database of the SENSATION project. The Pilot 2.5 experiments are presented in the next section.

We proposed to that the blinks be located by analysing the EOG velocity and to characterise the vertical EOG behaviour during an ideal blink as shown in Fig. 1. According to this blink model, the eye closure phase starts at the time debh and stops at finh, and the opening phase starts at debb and finishes at finb.

The values of Vcl (closing velocity threshold) and Vop (opening velocity threshold) were empirically selected after analysing a set of EOGs recorded during biocalibration tests. Bio-calibration tests were performed before the tests, for each driver, in order to determine the personal characteristics of EEGs and EOGs during specific conditions: relaxed, closed or open eyes, etc. During these experiments, the subject was wide-awake.

The software that we developed to locate the blinks implements the following steps:

**Step 1:** The left and the right vertical EOG are filtered in order to remove the frequencies above 10 Hz. The right channel only is used when the left channel is not available.

**Step 2:** The first-order approximation of the filtered EOG velocity

\[
\frac{d\text{EOG}}{dt} \approx \frac{\text{EOG}((k + 1) \cdot T) - \text{EOG}(k \cdot T)}{T}
\]

is computed.

**Step 3:** All the sequences where a period of the EOG velocity above Vcl is followed by a period below Vop are located. These sequences, hereafter called *events*, cor- 