MODELLING SLEEP WITH GAUSSIAN MIXTURE MODEL BASED ON EYE MOVEMENTS AND DELTA-ACTIVITY

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ABSTRACT

The automatic sleep analysis is difficult task. The signals needed to perform the analysis are at least EEG and EOG. In this paper, the analysis is made mainly by using the EOG signal, and only the part of the EEG signal, the delta-band. The Gaussian mixture model (GMM) is calculated from the signals after detection of the eye movements and the processing of the EEG signal. The results show the eye movements and the delta-activity can be used to make discrimination between different sleep stages, although some additional signals, for example EMG, might improve the analysis.

1. INTRODUCTION

This study is part of SIESTA-project, which aims at developing a new standard for sleep scoring. One of the biggest disadvantages of Rechtschaffen & Kales sleep scoring manual (R&K) [1] is the coarse time resolution of 20 or 30 seconds. In the SIESTA project, time resoltution is choosen to be 1 second. Another disadvantage of R&K is the too small number of sleep stages. SIESTA aims at a continious sleep depth plot including wakefulness and REM sleep.

Eye movements and high amplitude delta-activity are known to be good measures for certain sleep stages. Eye movements should only appear, according to R&K, in stages WAKE (wakefulness), S1 (first stage of sleep) and stage REM (Rapid Eye Movement) sleep. On other stages (S2, S3 and S4) there should not be eye movements.

Delta-activity is important feature for sleep staging. Delta-activity is very high at sleep stages S3 and S4 and rather low at stages WAKE and REM.

In this paper, a method to model sleep with eye movements and delta-activity (activity between 0.5 and 3 Hz) is presented. The method uses Gaussian Mixture Model (GMM). A test is performed how well sleep stages are separable with these features alone.

2. MATERIAL AND METHODS

Data used in this study is from the SIESTA sleep recording database. All the recordings are full night recordings and have two Electrooculgram (EOG) channels and at least six EEG channels. Also other channels are included, but not used in this study. Data is scored by two or three human scorers (third scorer is a consensus scorer) according to R&K.

The GMM was developed with four recordings and tested with three recordings. All subjects were healhty subjects without sleep disorders between age 24 and 51.

Eye movements are detected with method developed by Värri et. al. [2] Modification to method has been made to improve the changing of blink, saccade and SEM detection treshold values. In the original method, the treshold value was set to 10 μV. In the method in use, the treshold value is calculated for each recordings with following way: 1) Standard deviation of the recording is calculated in 90 second window. 2) The median value of the standard deviations is choosen to the new treshold value. With the recordings used in this study, the treshold values were between 5 to 22 μV.Because the method was developed to be used with a 100 Hz sampling rate, all the data is downsampled to 100 Hz, if necessary.

The output of the eye movement detection algorithm is then converted to 1 Hz signal. The maximun value of eye movements within 1 second window is choosen as the output (1).

$$y(j) = \max(x_{(j-1)*100+i}) \quad ,i = 1,2,\ldots,100 \quad (1)$$

where j goes from 1 to the number of seconds in the recording. Example of the output can be seen in the figure 1.

The number of eye movements can vary rather much between different recordings. Also the distance between eye movements can vary even on REM sleep stage [3] and relatively long sections (over 30 seconds) of the sleep can be scored as REM sleep according R&K sleep scoring manual without eye movements. Therefore the signal *y(j)* is filtered with relatively long (order of 100) weighted mean filter (2a).

$$wm_p(n) = \begin{cases} n & ,1 \le n \le N/2 + 1 \\ N + 2 - n & ,N/2 + 1 < n \le N + 1 \end{cases} \quad (2a)$$

Filter coefficients are normalised:

$$wm(n) = \frac{wm_p(n)}{\sum_{1}^{N+1} wm(n)} \quad ,n = 1,2,\ldots,N+1 \quad (2b)$$

where N is the order of the weighted mean filter.

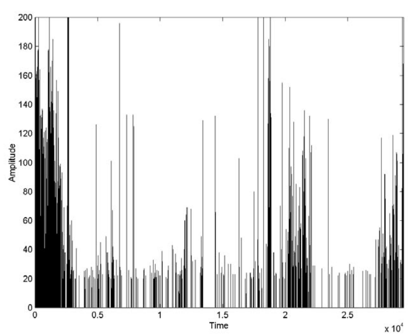

Figure 1. Detected blinks (recording c000902) after conversion to 1 Hz signal

The output of the weighted mean filter is mapped to a new scale, where values varies from 0 to 1 with equation 3:

$$y(j) = 1 - e^{(-x(j))} \quad , j = 1,2,\ldots,K \quad (3)$$

where *K* is the length of the input signal. In the figure 2, example of the mapping can be seen. The mapping improves the results of the method presented in this paper.

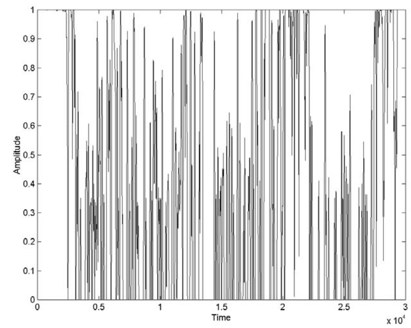

Figure 2 Detected blinks after mapping to the new scale.

In the figure 3, the mapped blink signal is divided according the R&K scoring. The differences between the stages can clearly be seen

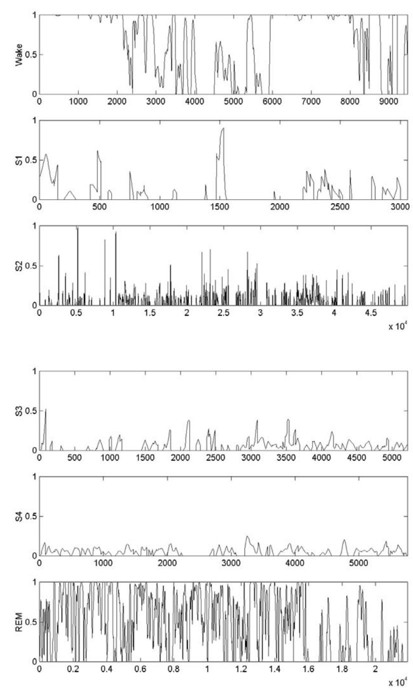

Figure 3. The value of the mapped blink signal at the different sleep stages. The stages Wake and REM has clearly bigger values than the other stages.

The GMM is made for the output of the scaling function. In case of two hypnograms, the data sections where two scorers agreed, was taken into account. Mean and variance of each sleep stage were calculated and used as parameters for The GMM. Also priorities for all sleep stages were calculated. The probability density functions for each sleep stage were calculated (4)

$$p(x|\omega_s) = \frac{1}{\sqrt{2\pi\sigma_s}} e^{-\frac{(x-mean_s)^2}{2\sigma_s^2}} \qquad (4)$$

where $mean_s$ is mean value for stage s = WAKE, S1, S2, S3, S4 and REM and σ is the standard deviation for each sleep stage. The probability that the input x comes from sleep stage ω_s, is then (5a)

$$p(\omega_s|x) = \frac{p(\omega_s)\,p(x|\omega_s)}{p(x)} \qquad (5a)$$

where $p(\omega_s)$ is the probability of the sleep stage s and $p(x)$ is the probabilty for x. Because for each x, the probability is always same, equation 5a can be written (5b)

$$p(\omega_s|x) = p(\omega_s)\,p(x|\omega_s) \qquad (5b)$$

The input x is then labeled to the sleep stage s where $p(\omega_s|x)$ has the largest value.

The delta-activity is processed with following methods: 1) EEG signal is filtered with a bandpass filter (bandpass 0.5 - 3 Hz). 2) From the output of the bandpass filter, peak to peak value is calculated for each second. 3) This output is then filtered with a median filter length of 11. 4) The GMM for the delta-activity is then calculated same way as the GMM for the eye movements. In the figure 4 the delta-activity of the recording c000902 can be seen.

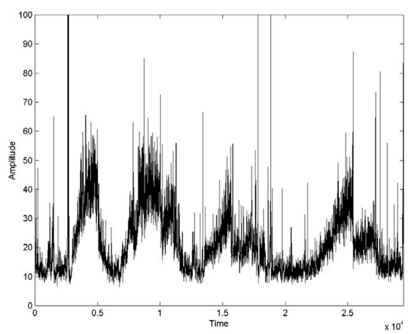

Figure 4. The delta-activity of the recording c000902.

Table 1
The Means and the standard deviations of the different sleep stages and signals. Next to the sleep stages, the priorities of the each stage are shown.

Signal	Mean	STD
	Wake (0.0994)	
Blink	0.7478	0.1451
Saccade	0.6705	0.1427
SEM	0.7688	0.1323
OEM	0.8546	0.0800
Delta-activity	19.0729	213.7850
	S1 (0.0321)	
Blink	0.1603	0.0658
Saccade	0.0742	0.0251
SEM	0.7301	0.1413
OEM	0.7001	0.1418
Delta-activity	21.8058	78.7138
	S2 (0.5236)	
Blink	0.1020	0.0340
Saccade	0.0157	0.0062
SEM	0.3467	0.1985
OEM	0.3457	0.1693
Delta-activity	29.5562	105.1256
	S3 (0.0548)	
Blink	0.2244	0.0574
Saccade	0.0149	0.0047
SEM	0.1110	0.0752
OEM	0.2114	0.0839
Delta-activity	50.3393	281.8534
	S4 (0.0604)	
Blink	0.2866	0.0518
Saccade	0.0211	0.0053
SEM	0.0168	0.0096
OEM	0.2774	0.0908
Delta-activity	65.4955	426.5462
	REM (0.2297)	
Blink	0.5963	0.1586
Saccade	0.5344	0.1511
SEM	0.8426	0.0884
OEM	0.7599	0.1154
Delta-activity	19.3708	31.2684

3. RESULTS

The results of determining the correct sleep stage by using eye movement and delta activity information for two different lengths of weighted mean filter are shown in Table 2. The three GMMs have been generated with both with and without delta activity. In the first GMM, all the different sleep stages were processed separatly. In the second case, sleep stages S1-S4 have been processed as a single sleep stage and in the third case also sleep stages WAKE and REM are processed as one sleep stage. The results are given as percentages of correct classifications of sleep stages in comparison to the visual scorers of all 30 s epocs of the night. The example of the output of the GMM for the case 3 can be seen in the figure 5.

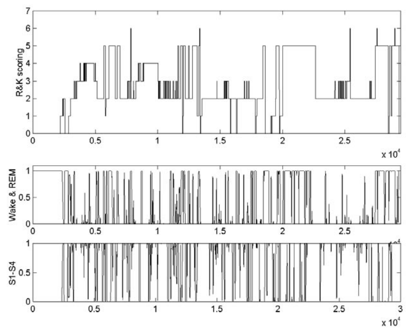

Figure 5. At the top is the R&K scoring of the recording c000902. Athe middle the probabilty of the Wake and REM and at the bottom the probability of the stages S1 to S4

Table 2
Percentages of correct sleep stage scorings by using eye movement detections and delta activity. For an explanation of the cases see text above.

	With delta-activity	without delta-activity
N=100		
Case 1.	71.73 %	66.83 %
Case 2.	82.95 %	82.21 %
Case 3.	90.01 %	89.24 %
N=50		
Case 1.	69.22 %	64.88 %
Case 2.	80.79 %	80.16 %
Case 3.	87.57 %	86.37 %

4. DISCUSSION

In the case 1, the GMM with delta-activity obtained better results compared to the GMM without delta-activity. The reason for that is the lack of eye movements in the sleep stages S2, S3 and S4. The percentage of the sleep stage S1 was also very small in the test recordings. In the case 2, where the sleep stages S1, S2 S3 and S4 were combined, the delta-activity did not have so significan improving effect as in the case 1. In the case 3., when also the sleep stages WAKE and REM were combined, the effect of delta-activity was also very small. The length of the weighted mean filter had also some effect: the longer filter improved the results.

This experiment has shown the power of eye movement detections in sleep stage scoring. When eye movement detections are combined with delta activity and other advanced EEG and EMG measures, a good estimate of the subject sleep depth can be obtained. The discrimination between stages S2, S3 and S4

5. ACKNOWLEDGEMENTS

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