Automatic Detection Of Sleep Disorders With The Help Of Commercial Microphones Based On Speech Recognition Methods

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Abstract

Lots of medical studies pointed out that approximately 20-30 percent of the German population suffer from sleep disorders. Immediate consequences are fatigue and lack of concentration. If the causes of these disorders are not diagnosed and therapied at an early stage, they can lead to hypertension, cardiac disorders and depression. That is why we tried to detect and mark those sleep disorders with the help of a commercial microphone, which is placed near the larynx of a patient. In order to detect the sleep apnoea syndrome, we used standard methods and algorithms from speech recognition. Good results could be achieved with the linear predictive coding (LPC). Furthermore, a heuristic energy function was developed to detect phases of reduced flow of breathing. The advantages of the system are low costs, only using one single sensor and its automatic detection and classification of sleep disorders.

1 Introduction

The so called sleep apnoea syndrome belongs to the acute sleep disorders and is characterized by frequently apnoeas. The medical definition includes a minimum 10sec. interval between breaths [1]. If the flow of breathing is reduced within a certain period, this syndrome is called hypopnoea. Both syndromes are accompanied by continuously snoring and involve lots of consequences such as hypertension, cardiac disorders and depressions. Our idea was to use a commercial larynx microphone (see **fig. 1**) and to record the resulting sounds of breathing and snoring. Larynx microphones have the advantage not being sensitive for noise of the environment. Consequently, we already have acquired a good signal without any pre-processing algorithms.

Fig. 1 Commercial larynx microphone (left); positioning of the microphone next to the larynx of the patient (right)

The typical process of a sleep apnoea event is shown in **fig. 2**. We can identify an apnoea event of approximately 30sec. after snoring intervals of about 4sec. Apnoea events are finished by so called arousals that correspond to the rehabilitation of breathing. A naive algorithm could easily locate this arousal after detecting at least a 10sec. interval between breaths. The disadvantage of this method is obvious: We can only use this algorithm to analyze a data stream, but it does not permit the detection of the beginning of sleep apnoea events in real time.

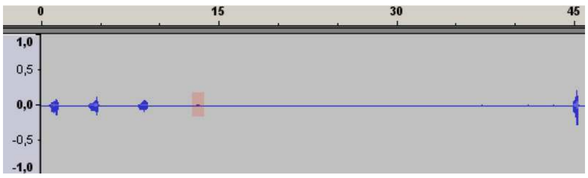

Fig 2. The typical process of a sleep apnoea event

That is why we have to look for characteristic features predating the beginning of a sleep apnoea event. Such feature is marked in **fig. 2**. It sounds like a short strong snoring, sometimes associated with a touch of groaning. Unfortunately, this feature could not be found before all sleep apnoea events and it varies from patient to patient.

2 Materials and Methods

2.1 Detection of sleep apnoea events

In order to detect the beginning of a sleep apnoea event we tried to model the characteristic feature marked in **fig. 2**. Therefore we used a standard method from speech recognition: The linear predictive coding (LPC). It is based on the idea to compute an estimated sample from *m* former samples [2]:

$$\hat{f}_n = -\sum_{\mu=1}^{m} a_\mu f_{n-\mu}$$

With this model we can extract a feature vector ***a*** from the characteristic samples ***f*** marked in **fig. 2**:

$$\begin{pmatrix} f_k & f_{k-1} & \cdots & f_1 \\ f_{k+1} & f_k & \cdots & f_2 \\ \vdots & \vdots & \ddots & \vdots \\ f_{n-1} & f_{n-2} & \cdots & f_{n-k} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_k \end{pmatrix} = \begin{pmatrix} f_{k+1} \\ f_{k+2} \\ \vdots \\ f_n \end{pmatrix}$$

This linear equation can be solved numerically, for example, with the singular value decomposition (SVD). After computing a reference vector ***r*** (see **section 2.3**), the beginning of a sleep apnoea is found, if the Euclidian distance between the reference vector and the actual computed vector is smaller than a threshold. Due to the requirement of detecting the sleep apnoea event in real time and our knowledge about the minimum duration of an apnoea event, we can formulate the following pseudo code algorithm:

```
IF( apnoe_feature detected ) {
      start_time = getTime();
      PRINT("Potential apnoea event starts");
}
IF( arousal AND (getTime()-start_time) >= 10sec ) {
      PRINT("Arousal detected");
}
```

The code shown above combines the detection of the beginning of an apnoea event in real time and the detection of the arousal as an indication for the end of a sleep apnoea. Furthermore, it considers the medical knowledge about the minimum time between breaths. Therewith, a high sensitivity can be achieved.

2.2 Detection of hypopnoea events

The following heuristic energy function was applied to detect hypopnoea events in the signal stream:

$$E = \int_{-\frac{w}{2}}^{\frac{w}{2}} s^2(t)dt$$

It sums up the signal amplitudes within a data window of about 200ms. If the signal energy lies between a maximum and a minimum threshold during a minimum 10sec. interval, a hypopnoea event can be the reason:

```
IF( (actual_energy >= min_energy) AND
    (actual_energy <= max_energy) ) {
      start_time = getTime();
}
IF( arousal AND (getTime()-start_time) >= 10sec ) {
      PRINT("Hypopnoea detected");
}
```

Due to the fact that the algorithm has to analyze the signal for more than a few milliseconds, no real time detection of a hypopnoea is possible.

2.3 Training

The reference vector ***r*** that models the characteristic beginning of a sleep apnoea event was computed by averaging over all available and extracted features. The energy thresholds to detect hypopnoea events have been determined empirically.

3 Results

The developed algorithms were evaluated with the signal streams of two different sleep apnoea patients. The results were compared with those ones detected semi-automatically in a sleep laboratory supported by a physician. The following table shows the obtained sensitivity and specificity [3]:

	Sensitivity	Specificity
Apnoea events	>60%	>70%
Hypopnoea events	>80%	>70%

4 Discussion

The presented results [3] show that it is possible to detect sleep disorders with commercial microphones. In contrast to the current state of the art, we do not need several modalities, for example ECG, EEG etc., but only one single sensor to detect sleep disorders. That is why the presented methods guaranty a minimum of exposure for the patient. Further research has to employ with alternative algorithms and microphones that improve both sensitivity and specificity.

5 References

[1] Schlafapnoe-Syndrom und Schnarchen, P. Hannemann, Jopp bei Oesch, Zürich (2000)

[2] Klassifikation von Mustern, H. Niemann, Springer, Berlin (1983)

[3] Aufnahme und Automatische Auswertung der Atemgeräusche von Schlaf-Apnoe Patienten, M. Struck, Studienarbeit (2006)