Portable Obstructive Sleep Apnea Detection Device Based on Bone Conduction Microphone

Yuan Wei and Jianguo Wei
The School of Computer Software, Tianjin University Beiyangyuan Campus, No. 135, Ya Guan Road, Jinnan District, Tianjin, China
Email: w0130@qq.com

Abstract. Snoring is a common physiological phenomenon but it is also an important sign of a life-threatening sleep disorder called Obstructive sleep apnea (OSA). Studies show that OSA affects 14% of men and 5% of women while many patients remain undiagnosed because of the high cost of professional hospital examination. We designed a wearable, portable device based on bone conduction microphone which allows users to perform OSA preliminary screening by themselves at home. Bone conduction microphone is adopted to achieve high quality signal recording while keeping the device convenient to use. Snoring sound recording won't be affected when people turn over during sleep. After snoring signal recording, a part is recognized with Hidden Markov models (HMMs) as the basis for diagnosis of OSA.

1. Introduction
Snoring is a common physiological phenomenon usually overlooked by people. Snoring may be harmless, but it is sometimes accompanied by a life-threatening sleep disorder called sleep apnea [1]. Sleep apnea reduces sleep quality and makes people feel tired during the day. It can also lead to cardiovascular disease. There are three types of Sleep Apnea Hypopnea syndrome (SAHS): obstructive, central and complex. Among them, Obstructive sleep apnea (OSA) is most common and has the highest incidence in the population [2]. Recent studies suggest that it affects approximately 14% of men and 5% of women [3]. The prevention and treatment of OSA needs extensive attention from the whole society.

The gold standard diagnostic test for sleep apnea is polysomnography (PSG) during an entire night [4]. The PSG usually consists of recordings of various biological signals, including electroencephalography (EEG), electrocardiography (ECG), electromyography (EMG), airflow signal, and oxygen saturation (SaO2) [5]. Several wires and electrodes must be attached to suspected OSA patients during signal recording, which makes it difficult for patients to fall asleep. OSA diagnosis through PSG is time consuming, labor intensive and expensive. Many patients remain undiagnosed because of the high cost.

In order to allow people to carry out a preliminary test at home without a doctor’s help, we designed a wearable, portable device based on bone conduction microphone and snoring signal analysis. People are required to wear this device during sleep. Then snoring, breathing and apnea are recognized according to the sound recorded at night. Snoring signal is recorded using a bone conduction microphone in this study because bone conduction microphone shows great advantage over air conduction microphone in this audio recording task. Air conduction microphone is easily affected by ambient noise. Besides, air conduction microphone must be placed near people's mouth while recording. There will be a problem when people turn over during sleep.
2. Related Work

Many features of snoring signal have been analysed before, such as fundamental frequency [6], power ratio and formant [7]. These features in time domain and frequency domain can contribute to the diagnosis of OSAHS.

Ng’s work showed air conduction microphone should be kept 0.3m away from the patients’ mouth to achieve optimal signal quality with minimal patient discomfort [8]. Sola-Soler analysed the pitch of snoring signals. Differences in pitch parameters were found between simple snorers and OSAS patients [9]. Based on a hypothesis that there is a difference between the speech characteristics of OSA-patients and non-OSA subjects, Kriboy presented an automatic system for diagnosing OSA from speech [10].

There are also some portable devices proposed before. Alshaer introduced a wearable face frame recording breath sounds and airflow during sleep [11]. The face frame can record both sound and airflow signals, but it is uncomfortable to wear during sleep. Hsu designed a device recording snoring signal using air conduction microphone. This device is intended to be put along the bedside as a clock [12]. Compared with the wearable bone conduction microphone used in our device, the air conduction microphone used in this device is put far away from the user. It can not catch weak signals like breath sounds.

Apnea event decreases blood oxygen level and then causes abnormal heart activities or high heart rate. Thus, many OSA detection methods with ECG signals are proposed by researchers [13]. Similar work based on other physiological signals like SaO2 [14], midsagittal jaw movement [15] and EEG signals [16] can also be found in literature.

3. Experiment

3.1. System Design

A hardware system is designed to accomplish the recording task. The system is composed of a bone conduction microphone, a mobile terminal, audio acquisition module and wireless communication module which sends recorded data to the mobile terminal.

The breathing sound recorded by the microphone is not strong enough for our analysis. So we added a pre-amplifier between the microphone and the audio acquisition module. But the energy of breathing and snoring varies greatly. After adding the amplifier, snore signal is magnified out of scope. To solve this problem, an automatic gain amplifier is used instead of common amplifier. The amplifier chip SA2011 is adopted to perform the automatic level control (ALC).

![Figure 1. Automatic Level Control](image)

3.2. Data Recording and Annotation

The respiratory department of the First Teaching Hospital of Tianjin University of Traditional Chinese Medicine provided us with the sleep monitoring room and professional equipment to get accurate diagnosis results of the subjects. We selected five men and five women as subjects. Eight hours of data was recorded for each subject. The information of the subjects is shown in Table 1.
Table 1. Basic information of the subjects.

| Number | Gender | Age | Datalength(hours) | Type          |
|--------|--------|-----|-------------------|---------------|
| 1      | female | 24  | 8                 | simple snore  |
| 2      | male   | 27  | 8                 | OSAHS         |
| 3      | male   | 35  | 8                 | OSAHS         |
| 4      | female | 38  | 9                 | OSAHS         |
| 5      | male   | 40  | 8                 | OSAHS         |
| 6      | female | 44  | 8.5               | OSAHS         |
| 7      | male   | 50  | 8.5               | simple snore  |
| 8      | male   | 52  | 7                 | OSAHS         |
| 9      | female | 55  | 8                 | OSAHS         |
| 10     | female | 57  | 8                 | OSAHS         |

After recording, data was annotated manually to build a dataset for model training and testing. Annotation is done with the software praat. Sound signals are labelled as 5 categories shown in Table 2.

Table 2. Symbols used for categories of the signals.

| Snoring | Breath | Apnea or hypopnea | Speak | Others |
|---------|--------|-------------------|-------|--------|
| sno     | bre    | sil               | spk   | a      |

As Figure 2 shows, snoring signals have large energy. The energy is mainly distributed in the low frequencies. While breath signals are weak. Sometimes it is hard to distinguish it from silence according to the waveform. We need to make a judgement by hearing. Snoring and breath usually happen at a steady pace, which makes the annotation much more convenient.

Figure 2. Waveform of snoring, breath and silence

3.3. Model Training and Testing
Hidden Markov models (HMMs) are employed to model these five types of sounds [17]. This method has been proved to be effective in the field of speech recognition. Mel-Frequency Cepstral Coefficients (MFCC) vectors are used as features of the sounds. Data of eight subjects is used as the training set. Data of the other two subjects is left for testing. We used a three-state HMM to model snoring and breath sounds and used single-state HMM to model silence. Both frame length and frame shift are set to 60ms. 77% correct rate is achieved in the recognition result.

The apnoea hypopnoea index (AHI) is used as a marker of OSA severity [18]. AHI is defined as the number of apneas or hypopneas occurring per hour during sleep. In our recognition result, Apnea or hypopnea is characterized by silence longer than 10 seconds between snoring and breath sounds.
4. Conclusion
In this study, a device based on bone conduction microphone is proposed which provides people with a convenient and inexpensive way to detect OSA. It can play an important role in early diagnosis and the subsequent treatment of OSA. In comparison with other similar devices based on snoring sound analysis, the application of bone conduction microphone guarantees high quality sound recording, which makes the device more usable. More data can be recorded in the future to get a better recognition result.

5. References
[1] Freitas L S, Furlan S F and Drager L F 2018 Obstructive Sleep Apnea and Metabolic Risk: an Update Current Sleep Medicine Reports 2 1-8
[2] Ryan C M and Bradley T D 2005 Pathogenesis of obstructive sleep apnea J. of Applied Physiology 99 2440
[3] Peppard P E, Young T, Barnet J H et al. 2013 Increased Prevalence of Sleep-Disordered Breathing in Adults American J. of Epidemiology 177 1006
[4] Chai-Coetzer C L, Antic N A, Hamilton G S, et al. 2017 Physician decision making and clinical outcomes with laboratory polysomnography or limited-channel sleep studies for obstructive sleep apnea: a randomized trial Annals of internal medicine 166 332-340
[5] Punjabi N M 2008 The epidemiology of adult obstructive sleep apnea Proc. of the American Thoracic Society 5 136
[6] Abeyratne U R, Wakwella A S and Hukins C 2005 Pitch jump probability measures for the analysis of snoring sounds in apnea Physiological Measurement 26 779–98
[7] Ng A K, Koh T S, Baey E et al. 2008 Could formant frequencies of snore signals be an alternative means for the diagnosis of obstructive sleep apnea? Sleep Medicine 9 894
[8] Ng A K, Zhi J H and Tong S K 2008 Effects of microphone position on snore signal quality and patient comfort Int. Conf. on Signal Processing (Beijing: IEEE) pp 2130–33
[9] Sola-Soler J, Jane R, Fiz J A et al. 2002 Pitch analysis in snoring signals from simple snorers and patients with obstructive sleep apnea Proc. of the 24 Int. Conf. of the IEEE EMBS (IEEE) vol 2 pp 1527–28
[10] Goldshein E, Tarasiuk A and Zigel Y 2011 Automatic detection of obstructive sleep apnea using speech signals IEEE Trans. on biomedical engineering 58 1373–82
[11] Alshaer H, Levchenko A et al. 2013 A system for portable sleep apnea diagnosis using an embedded data capturing module J. of clinical monitoring and computing 27 303–11.
[12] Hsu Y L, Chen M C, Cheng C M et al. 2005 Development of a portable device for home monitoring of snoring Biomedical Engineering Appl. Basis & Communications 17 176–80
[13] Song C, Liu K, Zhang X et al. 2016 an obstructive sleep apnea detection approach using a discriminative hidden Markov model from ECG signals IEEE Trans. on Biomedical Engineering 63 1532–42.
[14] Marcos J V, Hornero R et al. 2010 Automated detection of obstructive sleep apnoea syndrome from oxygen saturation recordings using linear discriminant analysis Medical & biological engineering & computing 48 895–902
[15] Senny F, Destine J and Poirrier R 2008 Midsagittal Jaw Movement Analysis for the Scoring of Sleep Apneas and Hypopneas IEEE Trans. on Biomedical Engineering 55 87–95
[16] Abeyratne U R, Swarnkar V, Hukins C et al. 2010 Interhemispheric asynchrony correlates with severity of respiratory disturbance index in patients with sleep apnea IEEE Trans. on Biomedical Engineering 57 2947–55
[17] Eddy S R 1996 Hidden markov models Current opinion in structural biology 6 361–5
[18] Shahar E, Whitney C W, Redline S et al. 2001 Sleep-disordered breathing and cardiovascular disease: cross-sectional results of the Sleep Heart Health Study American J. of Respiratory & Critical Care Medicine 163 19-25