Preliminary Study for the Personal Handheld Device based Snoring Detection in Ordinary Sleep Situation

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Abstract—**Snoring is one of the representative phenomena of the sleep disorder and detection of snoring is quite important for improving quality of daily human life. The purpose of this research is to define the noises of the ordinary sleep situation and to find its characteristics as a preliminary research of snoring detection. Differently from previous snoring researches, we use a built-in sound recording system of Smartphone for practical use in ordinary sleep condition, and recording was carried out in a general private bedroom. Especially, we designed the experimental protocol, including the various noises could be frequently occurred during sleep such as cough, music, talking, alarm, door open/close, fan, radio and footstep to make closer to the actual sleep circumstance. The sound data set was recorded during actual sleep from 10 normal subjects. Totally 44 snoring data set and 75-noise dataset is acquired and analyzed.**

I. INTRODUCTION

Snoring is one of the representative reasons disturbing good sleep. Snoring is known to affect over 60 % of adult men and 44 % of women over the age of 40 in the world [1]. It is widely encountered conditions that have a number of negative personal and social effects and associated severe health problems. The most common disease related to the snoring is Obstructive Sleep Apnea (OSA). An estimated 24 % of the men and 9 % of the women of 30-60 years are reported to have more than five apnea or hypopnea per hour of sleep and daytime hyper somnolence (excessive sleepiness), which constitute the minimal diagnostic criteria for the sleep apnea syndrome [2]. However, results have shown that most subjects (82 % of men and 93 % of women) with at least moderate sleep apnea did not receive a diagnosis [3]. The main reason of this situation is that the subject could not recognize the seriousness of the snoring because snoring is occurred during sleep. Moreover, simple, low-cost instruments for mass screening of the population have not commercialized yet. Indeed, manual recording by a person with a whole night respiratory sound is very time-consuming and an operator dependent task. Therefore, automatic sound recording technique is required.

Snoring could be measured easier compared with other physiological signal because snoring is a kind of acoustic signal and it can be measured by the non-contact manner. There have been several algorithms presented snoring detection based on sound recording. Most have been performed in a controlled space without noises and controlled signal quality using expensive recording system. For example, in previous studies, a commercialized high-performance microphone such as Sennhiser ME 64 condenser microphone with a 40-20,000 Hz ± 2.5 dB frequency responses was used for recording. Moreover, recording circumstance has been strictly controlled to minimize noise sound. For example, recording microphone was placed 15 cm over the patient's head during sleep in previous researches. This strict experimental condition makes hard using a snoring detection technique for a private care in actual condition. Also, there have been many researches to develop portable technology to provide personal care or Homecare [4]. However, previous studies require complex sensors and leads such as the airflow, oxygen saturation, effort and position. Moreover, they have the major disadvantage requiring an experienced medical technologist at the site of the test for an acceptable accuracy, sensitivity or specificity performance. In other words, the technique based on connected sensor on the body makes the devices difficult to use by untrained persons [4]. Therefore, some difficulties still remain in the snoring detection for personal sleep management. The most important subject of snoring detection researches is distinguishing between snoring and other nocturnal sounds or external noises. Unfortunately, simple monitoring of sound intensity on the Sternal notch is not sufficient to solve the problem, and more complex techniques of the signal processing and analysis need to be employed to properly define and measure snoring. From this point of view, snoring has been analyzed and measured on the frequency and time domain, and it should be analyzed with a particular acoustic technique to distinguish it from various noises [5].

The purpose of this research is to define general noises occurred during sleep and to find sound characteristics as a preliminary study of snoring detection in noisy circumstance. Differently from the previous snoring detection researches, our research is performed in an actual sleep situation at private bedroom using the personal Smartphone for personalized mobile healthcare.

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II. Materials and Methods

First of all, we construct the sound database in actual sleep circumstance to find the characteristics of noise during sleep condition, including snoring, and then we carried out pre-processing for more accurate measurement. We use Android Smartphone, GT-I9300 (Galaxy S3^{TM}) manufactured by the Samsung Electronics (Suwon, Republic of Korea) for snoring monitoring, and use the MathWorks (Natick, MA, USA) MATLAB^{TM} 2011b for analyzing recorded sound and developing snoring detection algorithm.

A. Sound Database

We define representative noises in sleep circumstance and record various sound sources. Representative 8 noises are listed up including various noise sources such as fan, radio, talking and footsteps. Each noise is generated artificially in actual sleep condition. For a sound recording, we implement a sound recording application on Smartphone. Developed application records sound automatically if the input sound level is greater than 3 dB compared with ambient noise level that recorded in the initial stage of recording. Once recording is started, it lasts 10 seconds at least, and recording will be stopped if the sound level is not reached to the threshold. Because snoring is usually repeated several times, multiple snoring events could be included in one snoring database. Experimental data were collected from 10 subjects in actual sleep circumstance.

Every subject has no respiratory disease and sleep disorder except for the snoring. Snoring sound was recorded with 8 kHz sampling frequency, and it is stored in the internal memory of Smartphone in real-time. The concept of environment setup for sleep recording is described in Fig. 1.

Recording device, personal mobile phone, is placed on the table or bed near the subject. Before experiment, subjects are trained to locate their Smartphone within arm's length. In actual sleep environment, both snoring and various noises are recorded simultaneously. Table 1 shows the sound database. Sound of alarm, and cough are recorded naturally and classified by checking by researchers and other noises are generated by artificially in the same circumstance. Every data was collected in ordinary bedroom and outside noise such as the horn is excluded in our experiment.

TABLE I. Recorded Sound Database

Type of sound		Number of sound Samples		Remarks
Noise	Alarm	33	75	Cell phone alarm
	Cough	8		Manually Selected
	Door	5		Artificially generated
	Fan	5		
	Radio	8		
	Music	5		
	Talking	6		
	Footstep	5		
Snoring		44		Each snoring sound sample could contain multiple snoring generated continuously

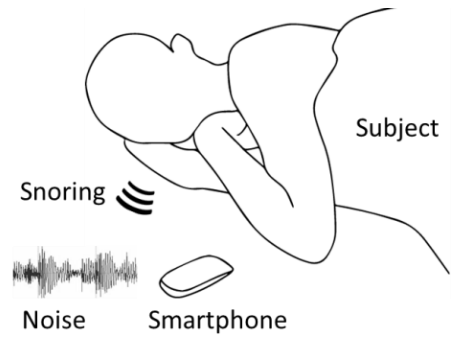

Figure 1. Environment of snoring recording.

B. Preprocessing

Because the sound during sleep should be recorded during the whole time of sleep, the extraction of the interest region of recorded sound is very important and should be preceded to distinguish the type of sound. Thus, in the first stage of the snoring detection, we extract the meaningful region of sound based on variation of sound level and duration of sustaining sound.

In order to extract snoring related parameters from the sound, each snoring episode should be detected in the first stage, while discarding unwanted sounds from other environmental noises. In preprocessing stage, first we divide the signal as multiple segments that have 0.1-second duration, and calculate the standard deviation for each segment. Then, we calculate the average of the standard deviation for 15 segments, and find the interest region, which over six times of average standard deviation of 0.1-second segments. Interest region is usually represented as numerous spikes from vibration, thus adjacent spikes should be interpolated to forming a meaningful region.

C. Formant Analysis

Though snoring is a kind of bioacoustic signal represented by sound, it includes both of the mechanical vibration of the upper airway and the acoustic sound. Previous researches try to find the characteristic of snoring, however, they could not reach to the consistent result. The frequency of snoring has differences in most researches from subject characteristic or

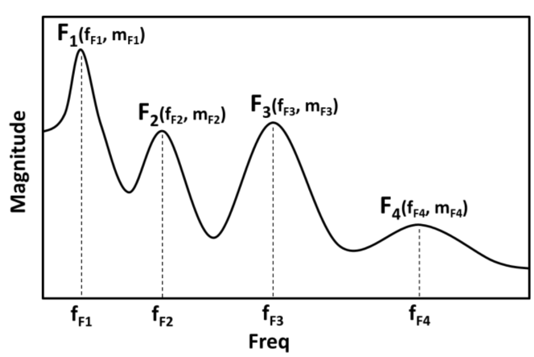

Figure 2. An Example of formant analysis. F_n means the *n*-th formant, f_{Fn} and m_{Fn} means the frequency and magnitude of *n*-th Formant, respectively.

experimental setup. In this research, we focused on the acoustic and mechanical characteristic of snoring. It is already known that the snoring from healthy people, without apnea episodes, has a fundamental frequency that ranged 110-190 Hz [6, 7] and the frequency components higher than 800 Hz in snoring patients with OSA [8, 9]. In this viewpoint, to define the frequency feature of snoring sound, we use the formant analysis and the formant is the frequency of maxima of the power spectrum of the snoring sound. In speech science, formant is also used to mean an acoustic resonance of the human vocal tract, and these properties could be used in snoring analysis as a kind of signal from human respiratory structure. Fig. 2 shows the example of formant analysis. In this figure, F_n means the n-th formant, f_{Fn} and m_{Fn} means frequency and magnitude of n-th formant, respectively. To derive formants from sound, autoregressive all-pole model parameters estimated by Burg method is used. In this research, we use 40-th order autoregressive model. The local maxima of the spectral density from autoregressive model, the formant, are detected by using a zero-crossing method.

III. Results

We derive formant from the recorded sound database. Fig. 3 shows an example of the formants of each sound source, in this figure power spectral density is derived by autoregressive burg model and it is represented up to 4 kHz that is half of the sampling frequency. The magnitude of formant derived in this experiment could not be compared with each other because recording distances are different according to subject and noises have not been normalized sound level assuming the practical use case. Formant shows a different aspect according to the type of sounds. For example, continuous and colorful sound such as alarm (a) or music (e) formants that have the relatively large magnitude and wider range of frequency. On the other hands, formant of monotonous sound such as door sound (c), talking (g) and footstep (h) shows that formants are concentrated in a specified range. Indeed, human eyes easily distinguish the difference of formant between colorful sound and monotone sound.

TABLE II. Quantitative Result of Formant Analysis

Type of Sound	Mean Value (Standard Deviation)					
	F_1 (Hz)	F_2 (Hz)	F_3 (Hz)	M_{F1} (a.u.)	M_{F2} (a.u.)	M_{F3} (a.u.)
Alarm	190.4 (15.1)	354.9 (38.1)	602.0 (118.9)	0.078	0.043	1.961
Cough	233.6 (58.8)	413.0 (85.5)	649.0 (121.3)	9.907	4.169	7.876
Door	152.5 (2.0)	296.0 (9.4)	516.1 (11.5)	5.705	1.874	0.708
Fan	233.2 (4.6)	331.2 (10.9)	529.1 (18.3)	0.586	0.44	0.383
Radio	208.4 (40.3)	418.9 (63.2)	646.7 (98.6)	0.105	0.229	2.792
Music	202.0 (17.0)	410.8 (89.1)	687.9 (123.0)	0.066	0.165	35.249
Talking	215.8 (47.8)	365.7 (49.2)	605.8 (246.5)	0.506	1.027	0.161
Footstep	171.1 (6.8)	284.6 (14.8)	498.1 (27.5)	0.729	0.168	0.205
Snoring	196.2 (21.5)	368.4 (81.7)	590.7 (115.6)	0.872	0.12	0.151

The unit of magnitude is represented as an arbitrary unit (a.u.) because the measuring distance is irregular in every experiment.

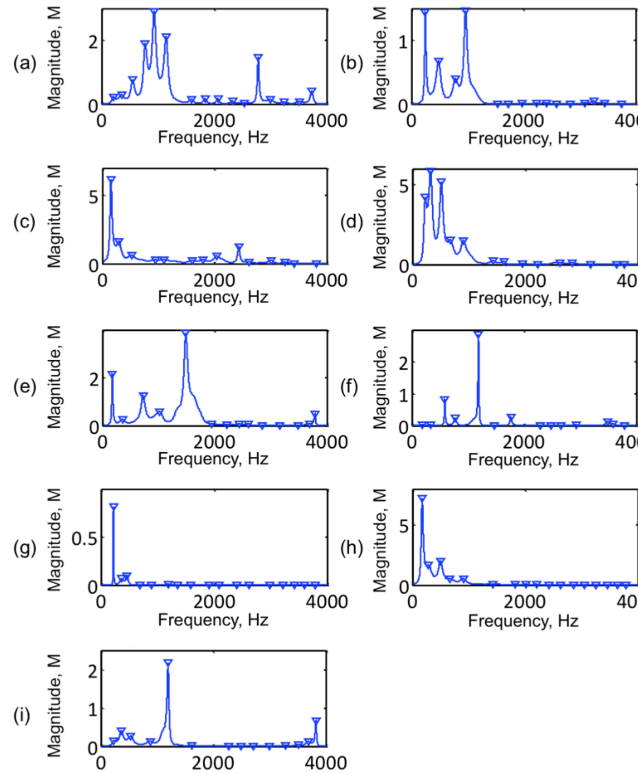

Figure 3. An example of formant analysis of sound generated during actual sleep environment. a) sound of device alarm, b) sound of cough, c) sound on door open/close, d) sound of fan, e) sound of radio, f) sound of music, g) sound of talking, h) sound of a footstep, and i) snoring.

Table 3 shows the quantitative result of formant analysis. The result includes the top 3 formant's frequencies and amplitude at each frequency. Formants have different trends in different sounds. For example, in case of alarm sound, the magnitude of third formant increases rapidly and in case of fan sound, the frequency of first formant is relatively higher than other formats. We could find the characteristic of each sound that recorded in actual sleep condition in the same manner. Amplitudes at each formant are described as an arbitrary unit because our experiment is carried out in non-controlled (practical) sleep condition. Thus, the distance between the subject's head and the recording system can be varied and it makes the difference of recorded sound level.

IV. Discussion

From the result of the formant analysis, we could find the characteristic of sounds occurring in sleep. Generally, formant of monotonous sound such as door, fan or footstep sound that generated by an object has a small standard deviation, but in case of colorful sound, including sound generated by human such as talking, cough or snoring, formant has relatively large variation. Moreover, we also found that the energy is concentrated around formant in monotonous sound, but the energy is spread around the formant in colorful sound. Snoring shows the relatively low standard deviation compared with other sounds generated by human such as cough or talking. In magnitude analysis, the power spectrum represented as formant shows wider distribution in most colorful sounds than in monotone sound. However, in snoring sound, we can find that the power spectrum is relatively concentrated around the specified formant. Absolute values of formant have the limitation to use in analyzing the characteristic of sound because we only use the built-in microphone of handheld device that specification is unavailable, and snoring sound was recorded in random distance on the bedside.

V. Conclusion

Snoring, as a representative sleep problem is a very important issue in sleep management because snoring could be a reason of serious sleep related disease such as obstructive sleep apnea and other complications. This research, as a preliminary study of snoring detection, designed to be performed in an uncontrolled private bedroom with a built-in recording system for practical use. Therefore, we develop the sound recording system based on personal handheld device and collect the various sounds that occurred in an actual sleep situation. Moreover, we investigate the characteristic of sounds during sleep. This research has the identical goal with previous researches, snoring detection, however, in the viewpoint of its application they are totally different because the previous researches concentrates on the characteristic of snoring itself but our research focus on the snoring detection in practical situations. Therefore, it is our belief that the result of this research may be utilized to develop the snoring detection technique based on a personal handheld device such as Smartphone.

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