ISSN: 0976-3031

International Journal of Recent Scientific Research

Impact factor: 5.114

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Volume: 6

Issue: 10

THE PUBLICATION OF
INTERNATIONAL JOURNAL OF RECENT SCIENTIFIC RESEARCH
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International Journal of Recent Scientific Research
Vol. 6, Issue, 10, pp. 6690-6694, October, 2015

International Journal of Recent Scientific Research

ISSN: 0976-3031

RESEARCH ARTICLE

CAN ACOUSTIC ANALYSIS OF SNORING PREDICT THE LEVEL OF OBSTRUCTION?

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Received 05thJuly, 2015 Received in revised form 08thAugust, 2015 Accepted 10th September, 2015 Published online 28st October,2015

INTRODUCTION

Obstructive sleep apnea (OSA) is a sleep disorder which is characterized by a continuous obstruction of the upper airways during sleep. Some of the consequences derived from OSA are a reduction of the cognitive functions, an augmentation of the risk for cardiovascular diseases, a decreased quality of life and increment of the sleepiness during the day.

Nowadays the most common way to diagnose the OSA is through a polysomnography. This is basically the recording of the snoring sounds which requires the patient to spend a whole night in the hospital. According to the shapes of the snoring sound, the doctor is able to diagnose if the patient suffers from OSA, and from which part of the vocal tract the snoring sound is produced. This is helpful, since there are some kinds of snoring that can be fixed through a surgery. However polysomnography has several drawbacks. Firstly, it is a very expensive procedure since the patient needs to sleep over in the hospital in specially equipped room. Secondly, the patient is not in the place where s/he usually sleeps which means that there is more tendency to have a bad rest and wake up at night. However the most important of the drawbacks is the difference between the snoring sound-waves that a patient emits when s/he is under a natural sleep, i.e., at home, and when s/he is under an induced sleep during the polysomnography test.

Nevertheless, polysomnography is not the only method by which a patient can be diagnosed as suffering from OSA. Another common technique that is used in snoring detection is nasendoscopy. This technique allows the speech technician to obtain accurate information about the upper airway of the patient by introducing an endoscope through his nose. Whilst it is not harmful it is known that this procedure gives a very uncomfortable feeling to the patient, making him sneeze, water his eyes or even feel a bit faint. On the other hand, there is a lot of research going on in the field of the non-invasive techniques, such as algorithms capable of detecting snores in an audio record and able to sort them according to the place of production in the vocal tract. These algorithms are a tool that the technician or doctor has in order to make an early, butstill not very accurate, diagnosis of the patient. The - algorithms examine snoring sound wave discrepancies and, by processing the sound signal of the patient detect the risks of suffering OSA. In literature two main algorithms seem the most efficient: short-time energy (STE) and zero-crossing rate (ZCR). STE measures the differences in the stored energy in the signal, while ZCR takes into account the times that the voltage value passes through zero. The pitfall from these algorithms is that the snoring sound must be clean, i.e., recognizable and noise free. Therefore, the audio recording must fulfil strict requirements regarding the distance and place of the recorder (many times between the eyebrows, in the throat, etc.) This makes it extremely uncomfortable for the patient, and again we risk to record signals coming from a bad night of sleep. The problem that we try to solve is to determine the level of obstruction of the vocal tract of a snoring patient using non-invasive techniques. This issue is of major concern since there are many people, usually male adults, who suffer from OSA. This disorder does not only affect the health of the patient, but also the relationship with his/her bed partner. The first thing is to understand the problem. Snoring can be produced in different areas of the vocal tract. The main areas are the palatal, the tongue and the epiglottis. The importance of this relies in the fact that if the palatal flutters, i.e., the snoring is mainly palatal, there is a possibility to undergo surgery to get rid of the snore. In any other case surgery is not a possibility.

In this paper we will focus in the development of a new algorithm in order to improve the methods abovementioned to detect the level of obstruction in snoring. To achieve this we will develop a system based on two algorithms: the first one will be able to filter non-snoring events from the snoring recording. The second algorithm will be capable to predict the place of the vocal tract where the snoring has been produced according to methods taken from literature.

Objectives

In order to achieve the goal of developing a working algorithm

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to properly detect OSA we have set the following objectives for our project:

1. Understanding the production of snoring and its acoustic characteristics.
2. Research on different techniques for analysis and processing of snoring sounds.
3. Development of an algorithm able to filter non-snoring sounds from snoring events.
4. Development of an algorithm able to determine the site of obstruction.
5. Validation of the algorithms using data acquired from patients.
6. Improvement of the algorithm based on feedback data from the validation step.

SWOT Analysis

In order to validate the viability of our project we have decided to write down our strengths, weaknesses, opportunities and threats in a SWOT-like chart (Fig. 1).

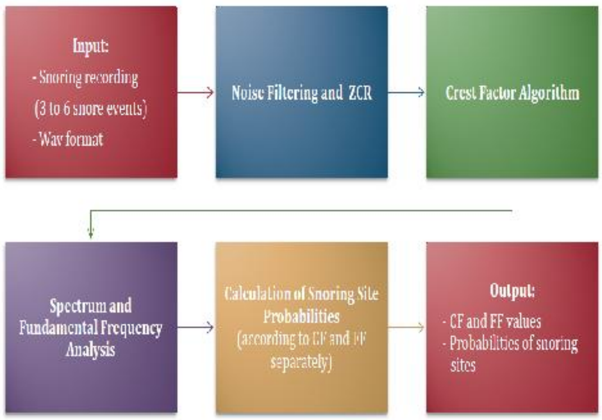

Figure 1. Overview of the algorithm.

STRENGTHS	WEAKNESSES
• Non-invasive technique • Information available in the literature.	• Difficulty of having an accurate validation of the algorithms due to the lack of data from patients.
OPPORTUNITIES	**THREATS**
• Easier diagnostics of the level of obstruction while snoring.	• Time limitation • Limited data and equipment.

Figure 1 Swot analysis

Problem Approach

In order to solve the problem of snore site classification, we will design a computational algorithm, programmed in MATLAB®, which will help a specialized doctor to validate the accuracy of the techniques in use. An overview of the system can be seen in Fig. 2.

The inputs are snoring recordings of a normal night sleep; the main goal is that simple recordings with a smartphone or computer can be used without need of special equipment. The signal is processed; filtered in order to eliminate unwanted noise from the snore events, then it is down sampled and normalized to make the analysis easier.

Two different techniques are used for differentiating snores according to the place at the vocal tract where they are produced; Crest Factor (CF) and Fundamental Frequency (FF). The outputs are the values of CF and FF, and different probabilities for each site of snoring according to both techniques. This information will serve as a preliminary analysis for the doctor, first to validate and if necessary modify parameters to improve accuracy, and at the end to make a diagnosis based on acoustic analysis.

Noise Filtering

The snoring signal does not only have a snoring component, it also contains a noise component such as white noise and any other sound that may appear during the sleep. The noises that we have taken into account in this study are alarm sound, noise of patient moving in bed, steps, wind, tap water running, and patient coughing. These kind of noises are not necessary and will disturb the proper functioning of the classifier algorithm. In this sense we need to eliminate them.

It is known that ZCR is not strong against noisy environment. In order to make a stronger algorithm we have set a previous filtering step. We have studied the spectrum of 12 snoring samples and15 noise samples. We conclude that the snoring has mainly two frequency ranges 200-1200Hz and 5-10 KHz, while on the other hand the noise has mainly a frequency range from 0 to 5 KHz. The idea is to keep the frequency spectrum of the snoring while filtering the noise frequency range. In order to achieve this goal we need a high pass filter with cut-off frequency of 200Hz, a band-stop filter with cut-off frequencies of 1,2KHz and 5KHz and a low-pass filter with cut-off frequency of 10KHz.

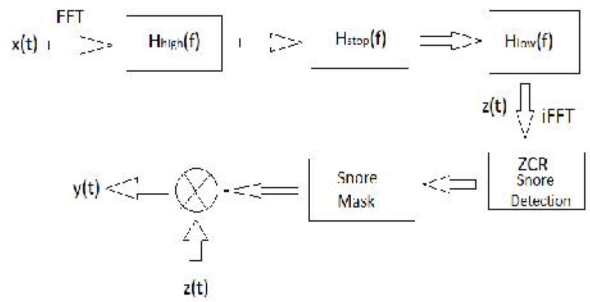

Figure 2 Overview of filtering algorithm

First of all we apply the fast Fourier transform (FFT) to the snoring signal we have from the patient. This signal is then passed through the different filters abovementioned. After the noise frequencies have been filtered, the inverse FFT (IFFT) is applied to get the signal back into the discrete domain.

The ZCR algorithm is a method that counts the number of times the signal passes through zero. It is known that unvoiced signals have higher ZCR than snoring and breathing events. Thus, this algorithm will be able to detect the snoring events. A binary mask will be created along with the detection of the snoring events. This binary mask is in fact an array which will be filled with ones when a snoring event is detected and with zeros when silence is present. The final step is to multiply this mask with the signal that we have got after the filtering process. By doing this, we have a snoring signal with only snores and no more noise in between snoring events.

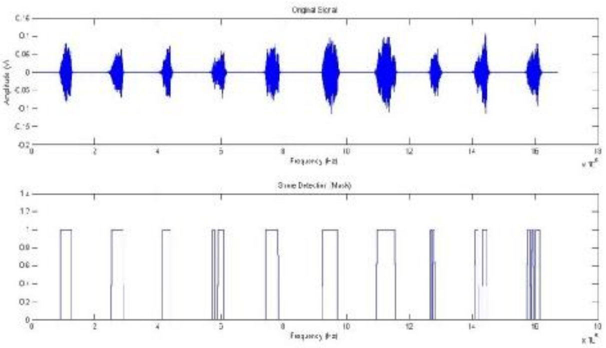

Figure 3 Original signal (above) and mask of that signal (below).

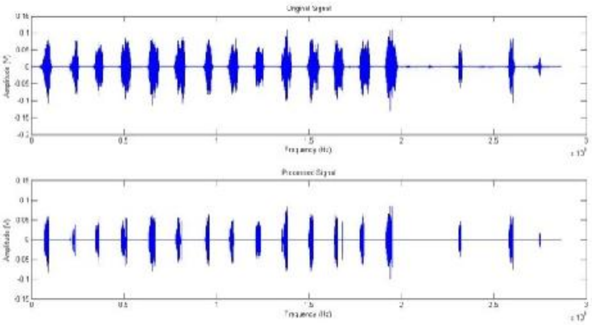

Figure 4 Original signal (above) and filtered signal (below).

Crest Factor

The peak ratio or Crest factor (CF) is a measure defined as the ratio between amplitude of a signal to its root mean square value, which has several applications in sound analysis. For snoring, based on published studies of sleep nasendoscopy for determining site of obstruction, the calculation of crest factor may lead to a valid differentiation between palatal and non-palatal snoring [1]. This is due to the fact that palatal snoring produces explosive peaks of sound at very low frequencies [2].

$$CF = \frac{V_{99}}{V_{rms}}$$

Based on these studies and their results, we have created an algorithm in order to calculate the Crest factor of a signal, composed by a series of snore events, and indicate the level of obstruction as a probability. The CF intervals selected based on the paper are:

- Hypo-pharyngeal: $CF \leq 2.4$
- Epiglottic: $2.4 < CF \leq 2.6$
- Tongue base: $2.6 < CF \leq 2.7$
- Palatal: $CF > 2.7$

Even though only palatal snoring is accurately determined with this technique, we have added the other intervals in order to give a suggestion of the possible site of snore. In Fig. 6, a signal is shown after being processed by the programmed algorithm, where the whole signal is divided into snore events, and within each event, it is divided into segments of 0.2s. From each segment, the peak ratio is calculated and then the mean for the whole signal is taken as the Crest factor for comparison with the intervals. If the CF is between a certain interval, the probability of that snore site will be 1 and 0 for the others.

Fundamental Frequency Analysis

Since CF is not enough for classifying snoring, spectrum analysis was considered and according to literature, a simple classification based on fundamental frequencies may be enough to make a second indication of the site of obstruction.

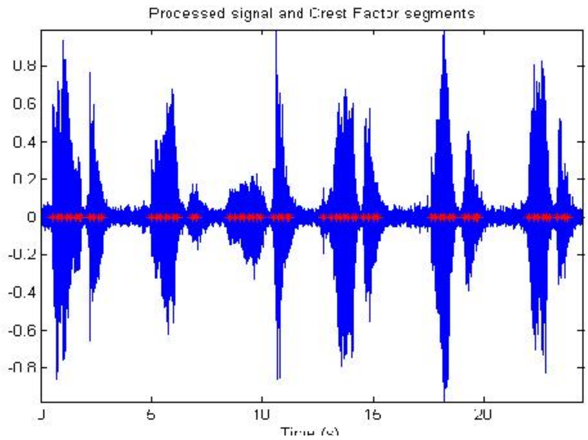

Figure 5 Processed signal showing segments used for calculating crest factor (red crosses indicate initial and end point of each segment).

Based on a polysomnography study and simultaneous recording of air pressures of the upper airway, Miyazaki et al. were able to compare sites of obstruction with the fundamental frequency (FF) of the snores [6]. Their results are the following, and in brackets the intervals selected for our algorithm are shown.

- Soft palate: 102.8 ± 34.9 [10:140] Hz
- Tonsils/tongue: 331.7 ± 144.8 [175:500] Hz
- Combined: 115.7 ± 58.9 [60:175] Hz
- Larynx: ± 250 [210:280] Hz

The algorithm created takes the input signal after filtering, down sampling and normalization, and calculates the Fast Fourier Transform (FFT) in order to form the spectrum, from which the fundamental frequency is obtained. Then according to the result, a probability is given to each snoring site where the FF is contained. If the FF is contained in more than one interval, the probability is reduced according to this division. The values of the intervals were taken arbitrarily, close to the results shown before from [6], but they can be modified in the algorithm once moredata after validation with patients is available.

RESULTS

Once the complete algorithm has been developed in MATLAB, we proceeded to the phase of validation based on snoring recordings with a previous diagnosis obtained from a clinician. Fig. 7 shows an example of the system interface showing the results for the analysis of one snoring recording.

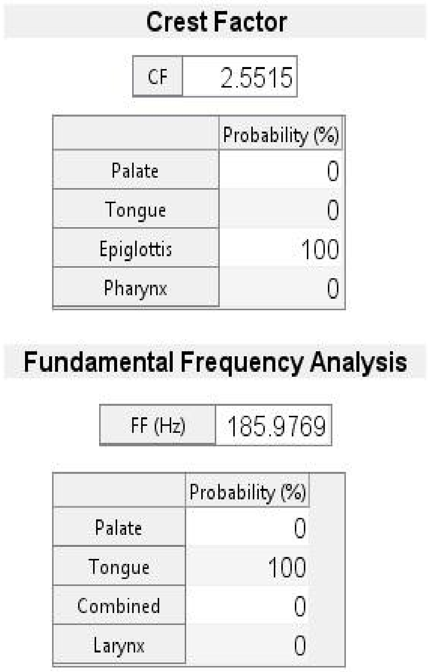

Figure 6 Results interface as shown in MATLAB for one tongue base snoring recording.

In order to validate the efficiency of the developed algorithm, a battery of snoring recordings has been analyzed. To accomplish this task, it is necessary to verify that the snore type that is given as a result of the algorithm is of the same type as the snoring diagnosed from a clinician. In our case, one larynx snore, one palate snore and five tongue based snores were evaluated. Table 1 shows the results obtained.

Table 1. Results obtained from the algorithm for the validation phase.

Snoring Type	Crest Factor (%)				Fundamental Frequency (%)			
	Palate	Tongue	Epiglottis	Pharynx	Palate	Tongue	Combined	Larynx
Larynx	0	0	0	100	0	0	100	0
Palate	100	0	0	0	50	0	50	0
Tongue 1	0	0	100	0	0	100	0	0
Tongue 2	0	0	100	0	50	0	50	0
Tongue 3	0	0	0	100	0	100	0	0
Tongue 4	0	0	0	100	50	0	50	0
Tongue 5	0	0	100	0	0	100	0	0

From the table it is noted that the algorithm is able to differentiate in the 100% of the cases palate-based snoring from non-palate based snoring according to crest factor results only. Crest factor is a good indicator to differentiate between these two kinds of snoring. On the other hand, this technique will say little about tongue, epiglottis or pharynx snores, for which probabilities are just a suggestion.

In case that Crest factor indicates non-palatal snoring, fundamental frequency has to be taken into account. Results from the table reflect coherence with the clinical diagnostic for most of the recordings analyzed. For most of the tongue based snoring files (3 out of 5) the algorithm was able to diagnose properly the snore as tongue-based. However, for larynx snoring and palatal, the algorithm is quite ambiguous to determine the site of obstruction. Nonetheless, it is important that for a complete case study, a sufficient amount of recordings for each patient is analyzed.

CONCLUSIONS AND FUTURE WORK

After having studied the results of the validation phase, it is clear that the algorithm is accurate enough to differentiate palatal from non-palatal snores based on Crest factor analysis only. For non-palatal snores the algorithm, based on fundamental frequency analysis, gives an approximation (in many cases close enough) of the type of snore that we might be dealing with. It is important that in practice, several recordings are analysed for a patient and their probabilities divided in order to obtain a more accurate suggestion of snoring type.

In our project, a full validation phase was not possible due to lack of sufficient recordings of previously diagnosed patients. However, the algorithm developed will be able to be used for a full validation in future work. Moreover, based on further research, the parameters on which both techniques in the algorithm are based can be modified so as to improve the accuracy of the results.

This work serves as a first approach in the development of a robust system for diagnosis of site of obstruction in snoring, using home recordings from simple devices. More techniques might be added in the future to complement the diagnosis but limitations on sound quality are a challenge.

Furthermore, the parameters used were based on previous statistical studies from literature, but a complete set of patients could be analysed based on the algorithm in order to improve it. So, with reference to the title of this project, "can acoustic analysis of snoring predict the level of obstruction?" The answer is still uncertain; however, a powerful tool has been developed in order to help solve this question.

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How to cite this article:

Maroto, Jaime and Marquez, Pedro and Moerman, MiekeVerdonck, Pascal.2015, Can Acoustic Analysis of Snoring Predict The Level of Obstruction?. *Int J Recent Sci Res.* 6(10), pp. 6690-6694.

International Journal of Recent Scientific Research

ISSN 0976-3031

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