Development of a portable device for home monitoring of snoring

Abstract

Snoring analysis is important for the diagnosis and treatment of sleep-related breathing disorders (SRBD). Snoring has traditionally been assessed in clinical practice from subjective accounts by the snorer and his/her partner. The use of polysomnographic recording is a standard evaluation procedure for SRBD patients. However, it is expensive and is not suitable for long term monitoring. This paper describes the development of a portable microcontroller based device for long-term, home monitoring of snoring. By analyzing the temporal feature of the snoring sound, this device can output the total snoring count, average number of snores per hour, and the number of intermittent snoring. In our tests, the average success rate in identifying snores is over 85% in a lab environment and around 70% in a home.

Keywords: Snore, SRBD, home monitoring, portable device.
1. Introduction

Snoring is a very common symptom and is an important sign of sleep-related breathing disorder (SRBD), such as obstructive sleep apnea syndrome (OSAS). Snoring analysis is important for the diagnosis and treatment of sleep disturbance. Snoring has traditionally been assessed in clinical practice from subjective accounts by the snorer and his/her partner. Various techniques have been developed for the quantitative measurement of snoring.

Cohen presented methods and algorithms for the quantitative and objective analysis of acoustical pulmonary signals such as breathing and snoring sounds [1]. Lopez et al. proposed a method to detect snores using an artificial neural network [2]. The frequency components of the pressure signals in the nasal mask of patients were fed to the neural network. In their test on 5 patients, the overall accuracy of correctly detected snores is 75.2%. Jane et al. also designed an automatic detection algorithm for acoustic snoring signals based on a neural network [3]. The input pattern of the neural network consists of 22 temporal and spectral features of the sound segment, which distincts between snoring sound and the remaining respiratory sounds. In their validation test, more than 500 snores taken randomly from the database of 30 subjects were analyzed. The sensitivity of the algorithm was 82%, and the positive prediction value was 90%.

Hoffstein et al. have pointed out that, the difficulty in measuring and quantifying snoring using objective criteria is that snoring is the first and foremost of a subjective perception by a listener [4]. They studied 25 patients, all had full nocturnal polysomnography including the measurements of snoring, to compare the objective snore count from the polysomnogram and the subjective snoring count by two listeners during a 20-minute segment. In their study, the objective count differed more than 25% in 7 out of 25 patents. In 7 out of 25 patients, the difference in subjective snore counts perceived by both listeners was larger than 25%.

The use of polysomnographic recording is a standard evaluation procedure for SRBD patients. However, it is expensive and is not suitable for long term monitoring. Penzel et al. developed a digital recording device called MESAM IV, to monitor oxygen saturation, heart rate, snoring, and body position in order to screen subjects for OSAS [5, 6]. They also indicated that this inexpensive implementation would allow the development of homecare systems for the analysis and long term monitoring of snoring.

The automatic scoring system of MESAM IV calculates oxygen desaturation index (ODI), heart rate variation index (HVI) and intermittent snoring index (ISI) to obtain an apnoea-hypopnoea index (AHI). The snoring sounds are recorded by means of a laryngeal
microphone. If the proportion of sounds between 50Hz and 800Hz exceeds 50%, it is assumed that there is snoring. Intermittent snoring is defined as intervals between two detected snores longer than 5 seconds and shorter than 60 seconds. Evaluating snoring interval analysis on 68 patients with all degrees of obstructive sleep apnea, Penzel et al. reported that correlation between snoring interval analysis and polysomnographically scored apneas was moderate ($r=0.51$) [6]. Following this development, a number of validation studies on MESAM IV were presented [7, 8, 9, 10, 11]. In those studies, the intermittent snoring index was found to have high sensitivity (92%-96%) but low specificity (16%-27%).

This paper describes the development of a portable device for home monitoring of snoring, which performs detection and selection of the snores, while discarding any other events that are present in the sound recording, as cough, voice, and other artifacts. Besides counting snores, this device also outputs the count for intermittent snoring. The measurement using this device with the subjective assessment is also compared.

2. Design of the snoring detector

Figure 1 shows the structure of the snoring detector developed in this research. Snores are low-frequency, regularly repeated sounds. In this device, a microphone records the snoring sound. The microphone used is an omnidirectional electret condenser type with a specified flat frequency response of 50-30,000Hz. High frequency sounds are then removed by a first order low-pass filter (cut-off frequency at 200Hz).
The analog signals are then sent to a microprocessor PIC16f877 to convert into digital signals. The sampling rate for the A/D conversion is 2kHz, and the resulting signals are shown in Figure 2(a). A series of smoothing procedures further process the signals:

1. The reference voltage is set to zero, and all signals are set to have positive voltage (Figure 2(b)).
2. The profile of the signals is extracted by finding the maximum voltage value in every 10 points (Figure 2(c)).
3. The peaks are amplified by taking the sum of every 10 points (Figure 2(d)).
4. The final profile is further smoothed by taking 10-point moving average (Figure 2(e)).

Note that at the end of this process in Figure 2(e), the sampling rate is reduced to 20Hz, and the vertical axis of Figure 2(e) becomes V_sum (sum of voltage in Figure 2(d), unit in mV).
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Figure 2(a). Original signal taken by a microphone and A/D converter at 2kHz

Figure 2(b). The reference voltage is set to zero, and all signals are set to have positive voltage
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Figure 2(c). Extraction of the profile by finding the maximum voltage value in every 10 points (200Hz)

Figure 2(d) 10-points sum to amplify the peaks (20Hz)
The snoring signals in Figure 2(e) are further analyzed by PIC16f877 microprocessor to determine whether a snore occurs. While most researches in snore analysis focus on the processing of the frequency content of snores, we focus on the temporal features of snore. To analyze the temporal features of the signals in Figure 2(e), the first problem is to determine when a snore starts and when a snore ends.

In this study, if the snoring signal in Figure 2(e) (Vsum) increases consecutively for 5 times (about 0.25 second), the 5th signal is defined as the start point of a snore. Similarly, if Vsum decreases consecutively for 5 times, the 5th signal is defined as the end point of a snore. The time between a start point and the adjacent end point is defined as Tduration, the duration of the snore; the time between an end point and the next start point is defined as Tinterval, the interval between snores.

We collected 5024 snoring samples from 5 patients who were diagnosed to have sleep-related breathing disorders. Tduration of 99.0% of these snoring samples ranged from 0.6 seconds to 1.8 seconds. Tinterval of 98.5% of these snoring samples ranged from 1.4 seconds to 4.0 seconds. Moreover, in our snoring samples, the maximum number of snores in one minute is 20, and the minimum number of snores in one minute is 12. So we define that the total length of a snore (Tduration + Tinterval) has to be from 2.8 (60/21) seconds to 5.5 seconds (60/11). Therefore a piece of sound signal has to satisfy the following 3 conditions repeatedly (at least 2 times) to be qualified as a snore:

**Figure 2(e). 10-point moving average to smooth the curve**
As mentioned earlier, in MESAM IV developed by Penzel et al. [1990, 1991], intermittent snoring was defined as intervals between two detected snores longer than 5 seconds and shorter than 60 seconds. This definition is also used in our device, that is, a piece of sound signal is detected as intermittent snoring if \( 5.0 \leq T_{\text{interval}} \leq 60.0 \). Figure 3 shows a piece of sample data in which some of the sound signals were identified as “snores”, and some of the sound signals were identified as “intermittent snoring”.

![Sample data](image)

**Figure 3. Sample data**

Figure 4 shows a prototype of the snoring detector developed in this research. The total number of snores and intermittent snores, as well as the average number of snores per hour can be shown on the LCD display in the front panel, or stored in the multi media card (MMC) for using in long term monitoring. The real-time clock chip DS1302 is also integrated to provide the date and time of the system. Therefore this device can also be used as a clock for home use. The user can switch from “normal mode (as a clock)”, “sleep mode (snore detection)” and “report mode (reading data)” from the knob and buttons on the front panel.
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3. Evaluation of the snoring detector

We did two tests to compare the subjective perception of snoring by a listener and the measurement by the snoring detector. In our first test, 4 10-minutes snoring sounds were recorded and played in a lab environment. The speaker and the snoring detector were placed in fixed positions. Each snoring sample was played 3 times. Table 1 shows the results of this test. The success rate in identifying the snores ranges from 74% to 96%. The success rate for snore sample C is lower because the volume of the snore sound is very low.

In our second test, we actually placed the snoring detector at the home of 3 patients for overnight monitoring. In the home environment, the snoring detector was placed along the bedside the patient. The relative positions between the snoring detector and the patient cannot be fixed, and there can be other noise interferences during the detection. We also recorded the snoring sounds overnight so that we could listen to the recording and compare the subjective snoring count with the measurement by the snoring detector. Table 2 shows the result. The success rate ranges from 66% to 79%, lower than that obtained in a lab environment. The successful rate for identifying intermittent snores ranges from 64% to 80%.
Table 1. Evaluation of the snore detector in a lab environment

<table>
<thead>
<tr>
<th></th>
<th>Snores counted by human</th>
<th>Number of snores detected</th>
<th>Success rate</th>
<th>Average success rate</th>
<th>Intermittent snores counted by human</th>
<th>Number of intermittent snores detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snore sample A</td>
<td>151</td>
<td>148</td>
<td>96%</td>
<td>96%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>145</td>
<td>96%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snore sample B</td>
<td>137</td>
<td>123</td>
<td>88%</td>
<td>87%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>121</td>
<td>86%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>124</td>
<td>88%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snore sample C</td>
<td>83</td>
<td>63</td>
<td>74%</td>
<td>74%</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62</td>
<td>73%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>64</td>
<td>76%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snore sample D</td>
<td>104</td>
<td>96</td>
<td>92%</td>
<td>91%</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>94</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>84</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Evaluation of the snoring detector in a home environment

<table>
<thead>
<tr>
<th></th>
<th>Snores counted by human</th>
<th>Number of snores detected</th>
<th>Success rate</th>
<th>Number of snores per hour</th>
<th>Intermittent snores counted by human</th>
<th>Number of intermittent snores detected</th>
<th>Success rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>1952</td>
<td>1292</td>
<td>66%</td>
<td>258.4/Hr</td>
<td>236</td>
<td>188</td>
<td>80%</td>
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<tr>
<td>Patient 2</td>
<td>2675</td>
<td>1833</td>
<td>69%</td>
<td>366.6/Hr</td>
<td>113</td>
<td>74</td>
<td>65%</td>
</tr>
<tr>
<td>Patient 3</td>
<td>1877</td>
<td>1485</td>
<td>79%</td>
<td>297.0/Hr</td>
<td>28</td>
<td>18</td>
<td>64%</td>
</tr>
</tbody>
</table>

4. Conclusions

This paper describes the development of a portable microcontroller-based device for long-term, home monitoring of snoring. This device is intended to be a home appliance and can be put along the bedside as a clock. By analyzing the temporal feature of the snoring sounds, this device can output total snoring count, average number of snores per hour, and number of intermittent snores. This information indicates the severity of snoring and the likelihood of having OSAS. In our tests, the average success rate of this device in identifying snores is over 85% in a lab environment and around 70% in a home.

“What sound is a snore” is a very subjective judgment, and snoring sound varies from person to person. In the device presented here we focused on analyzing the interval of snoring sound. In the early stage of this research, we tried to use information extracted from frequency of the sound to help judging what are snoring sounds but failed. However, we still believe that the average success rate of this device can be improved if frequency information is properly utilized.
References


