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Performance of a snoring noise control system based on an active partition

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ABSTRACT

This paper proposes an active partition that can be placed between a snorer and a non-snorer on a bed to reduce the snoring noise around the non-snorer ears by integrating a rigid finite size passive partition with a two channel active noise control system. The noise reduction performance of the passive partition on a bed with a headboard is studied first, where the effects of the height and the width of the partition are discussed. Due to the limited partition size, the attenuation for the low-frequency diffracted noise is not sufficient, so two loudspeakers are proposed to be installed on the partition as the secondary sources to increase the overall noise attenuation. Both numerical simulations and experiments are carried out to demonstrate the feasibility of the proposed integrated snoring noise control system, and the results show that the proposed active partition can achieve over 10 dB noise attenuation at non-snorer ears in the 1/3 octave bands from 80 to 1000 Hz.

1. Introduction

Snoring noise in sleeping can be up to 90–100 dB around the ears of the partner on the other side of the bed, which affects the partner's sleeping or even induces hearing loss [1]. Specialized ear plugs especially made of soft foam are an effective method of blocking snoring noise, nevertheless prolonged or frequently repeated use of ear plugs can result in infection (otitis externa or otitis media), hearing loss, discharge or meningitis, etc. [2,3]. Therefore a snoring noise control system based on an active partition is proposed in this paper, which integrates a passive partition with an active noise control (ANC) system to generate a quiet zone around the non-snorer's ears.

Local active control in a highly reverberant room usually can have a 10 dB quiet zone of one-tenth of the sound wavelength, so it has been used by some researchers to reduce snoring noise around the non-snorer head [4]. For a single channel feedforward ANC system, attenuations of continuous and stationary snoring noise were from 7 to 13 dB around the error microphone in 63 and 125 octave bands, and the characteristic dimension of the quiet zone is 30 cm [5]. With a similar system, above 10 dB of snoring noise attenuation at the non-snorer ear is obtained from 100 to 300 Hz on a double bed [6].

To avoid the acoustic feedback from secondary source to the reference sensor in the feedforward ANC systems, a single channel adaptive feedback ANC system is applied on a twin-size headboard to create a quiet zone [7]. The average snoring noise attenuation is about 5–10 dB at the non-snorer ears and the quiet zone is sufficiently large for non-snorer's head movement [8]. Kuo et al. proposed using both adaptive infinite impulse response (IIR) and finite impulse response (FIR) filters with feedback neutralization to minimize the acoustic feedback so that the an average attenuation reaches 15–20 dB from 100 to 300 Hz with a multi-channel ANC system [9].

In above references, the active noise control system is only effective for low frequency snoring noise below 300 Hz, but the residual components from mid to high frequency still affect the non-snorer. Although active headsets can have wider noise attenuation bandwidth [10], they are not suitable for the sleepers on beds. Therefore, a passive barrier is proposed in this study to be used with the active noise control system to reduce snoring noise from the mid to high frequency. In fact, active noise barriers have been studied by many researchers through the theories, simulations or experiments [11–16]. In the present research, the active partition is used to broaden the frequency range of snoring noise attenuation.

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The paper investigates the feasibility of an integrated active and passive system for snoring noise control. The snoring noise is measured first so that its characteristics can be discussed, and then simulations based on the finite element method are carried out to investigate the effects of passive partition dimensions on the noise attenuation as well as the performance of active control. Finally experiments are carried out to demonstrate the performance of the proposed system.

2. Snoring noise and the integrated noise control system

Snoring is associated with physical and functional defects of upper airway responses and generally occurs in patients having narrower upper airway than the normal ones [17]. Two forms of snoring are recognized. The first one is primary snoring due to vibrations on soft palate [17,18]. The second one, called obstructive sleep apnea snoring, is defined by instances of low level breathing or pauses in breathing during sleep. In the present study snoring sample is restricted to the primary snoring. The samples of a typical primary snoring noise recorded by the authors are shown in time and frequency domains in Fig. 1, where the snore (inspiration) segments and expiratory segments are manually marked in time domain. Two high noise level bands of the second snore are B1 from 75 to 350 Hz and B2 from 350 to 700 Hz as shown in Fig. 1(b).

Fig. 2 shows the proposed active partition placed between the snorer and the non-snorer to reduce the snoring noise, where two persons are assumed to be lying on the two sides of a double bed. The partition connected with the headboard is placed on the bed between the persons and two secondary loudspeakers are built in it. The right person is the snorer and snoring noise from his/her mouth is the primary noise. The left one is the non-snorer. Two error microphones are located near the ears of non-snorer separately to monitor and adjust the performance of the system.

3. Numerical simulations

The bed surface and the headboard in Fig. 2 are modelled by semi-infinite rigid surfaces. The snoring noise source is considered as a point source on a rigid sphere, and a rigid partition is located between the snorer and the non-snorer. The origin of the system is set at the intersection center of the bed surface and the headboard. Both of the heads' radii are 0.10 m. The centers of the spheres are at $(0.10, -0.45, 0.10)$ m and $(0.1, 0.45, 0.10)$ m respectively. The point source from the snorer's mouth is at $(0.18, -0.45, 0.16)$ m, the left ear and right ear of the non-snorer are at $(0.13, 0.55, 0.10)$ m and $(0.13, 0.35, 0.10)$ m.

By using a commercial finite element method software (COMSOL Multiphysics [19]), the model geometries are built and the sound field are calculated. The whole sound field is modelled by a quarter of a sphere, where the two orthogonal planes represent the bed surface and the headboard. To obtain a quarter free field, the field is surrounded by a spherical ring PMLs (Perfectly Matched Layers) with 1/2 wavelength thickness. The domain can absorb spherical wave along the radius radiating outside the spherical face and little sound reflects into the sound field. This implies that the reflections of the room ceiling and walls are neglected in the simulation. The maximum element size used in the simulations is 1/5 wave length.

In the simulations, the strength of the point source representing the snoring noise source is set to $10^{-4}\,\mathrm{m^3/s}$ at each single frequency. The sound speed is 340 m/s and the air density is $1.21\,\mathrm{kg/m^3}$. The insertion loss (IL) at each one-third octave band at the receiving points is defined as the difference between sound pressure levels before and after placement of the partition or active noise control,

$$IL = 10\log_{10}\left(\sum_{i=1}^{10} 10^{0.1L_{p0i}}\right) - 10\log_{10}\left(\sum_{i=1}^{10} 10^{0.1L_{pi}}\right) \quad (1)$$

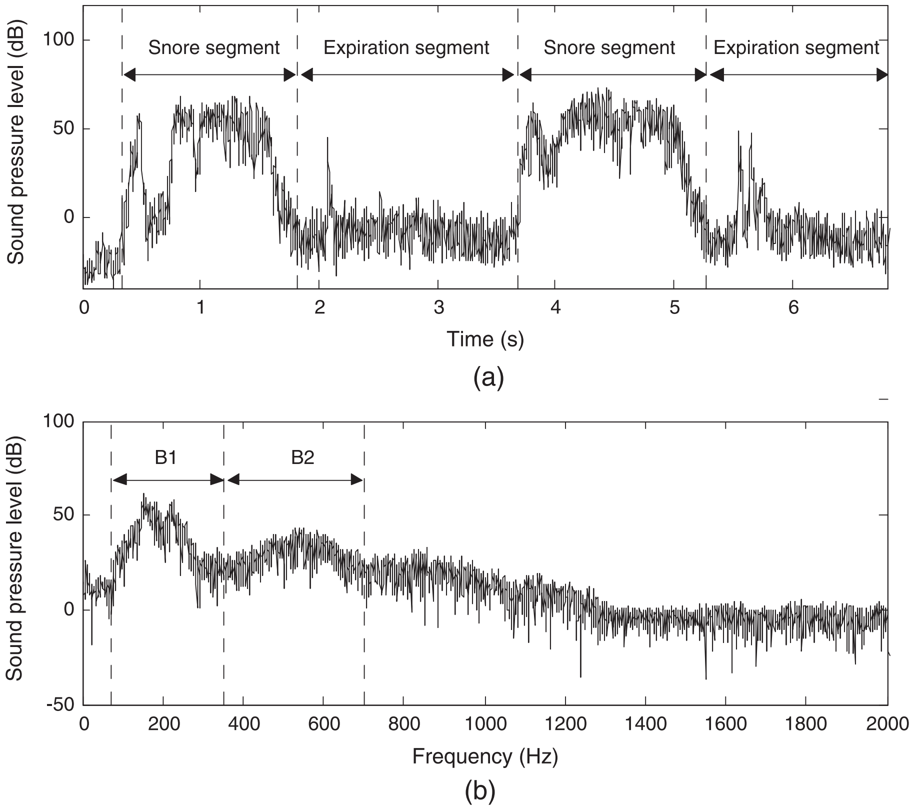

Fig. 1. The properties of a snore noise (a) waveform of a snore noise in time domain and (b) spectrum of the second snore segment.