Frequency characteristics of several non-audible murmur (NAM) microphones

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1. Introduction

A non-audible murmur (NAM) is a very weak speech sound produced without vocal vibration that can be detected using a specially designed sensor: a NAM microphone [1,2]. Nakajima invented the NAM microphone; several types of NAM microphone have been developed since then [2]. Because NAM sounds are not heard, the NAM is applicable for telephone systems that require privacy. Because air-conducted noise sounds are not mixed with sounds picked up by the NAM microphone, the device can eliminate the noise problems of automatic speech recognition systems [3]. The NAM microphone can also revive the speech communication capabilities of people with vocal cord problems caused by cancer of the larynx, nerve disorders, and muscle diseases [4]. However, the frequency characteristics and sensitivities of NAM microphones have yet to be revealed. This paper reports the frequency characteristics and sensitivities of five different types of NAM microphones.

2. NAM microphones

A NAM microphone comprises an electret condenser microphone (ECM) covered with a soft polymer material, such as soft silicone or urethane elastomer, which provides better impedance matching with the soft tissue of the neck (Fig. 1).

The specifications of five types of NAM microphone examined in this report are shown in Table 1. Figure 2 shows photographs of the microphones. The first, SS, is a soft-silicone-type NAM microphone manufactured by Mitsumi Electric Co., Ltd; an ECM whose diaphragm is exposed is covered with soft silicone and placed in a rigid cylindrical case of 30 mm diameter × 20 mm height. Figure 3(a) portrays an X-ray computed tomography scanning image of a soft-silicone-type NAM microphone. Its ECM is located at a very shallow position. The distance between the surface and the ECM diaphragm is about 2.5 mm. SSP1 and SSP2 are soft-silicone-type pseudo-NAM microphones manufactured by Mitsumi Electric Co., Ltd. A conventional ECM, whose diaphragm is not exposed, is covered with soft silicone and placed in a soft cylindrical case. The SSPs detect aerial vibration, unlike other types of NAM microphone. Therefore, we call them pseudo-NAM microphones. SSP2 is an improved version of SSP1.

3. Method

The frequency characteristics of the NAM microphones were measured using an audio analyzer (Pulse 3560C; Brüel & Kjær), an accelerometer (NR-3211; Ono Sokki Co., Ltd.), a bone conduction vibrator (BR-41; Rion Co., Ltd.), and a urethane elastomer cylinder of 75 mm diameter and 50 mm height, which simulates the soft tissues in the neck [5].

Figure 4 shows the measurement system. The vibrator is placed beneath the cylinder. A NAM microphone and the accelerometer are placed on the top of the cylinder. The accelerometer is covered with a silicone cover to align its height to the NAM microphone. A 1-kg weight is placed on top of the silicone cover to stabilize conditions in the NAM microphone and accelerometer. The vibrations transmitted through the cylinder are subsequently sensed by the NAM microphone and the accelerometer, and they are compared.

Let the measured frequency response of the accelerometer be \( A(\omega) \); then \( A(\omega)/\omega^2 \) gives the frequency response of the displacement. The accelerometer has a flat response of acceleration at frequencies less than 10 kHz. Because NAM microphones are displacement sensors, comparing the calibrated frequency response of the NAM microphone, \( D(\omega) \), with \( A(\omega)/\omega^2 \) yields the frequency response of the NAM microphone. The frequency response of the NAM microphone amplifier was compensated.

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4. Results

Figure 5 shows the mean frequency response of three SSs, three UEs, and a DUE. The mean frequency response of SS resembles that of UE at frequencies less than 2 kHz, except that the sensitivities are different at 1 kHz. The UE response has no peak at approximately 2 kHz, although the SS and DUE responses exhibit such a peak. At frequencies less than 0.4 kHz, both SS and UE have lower sensitivities. The frequency response of SS is lower at approximately 8 kHz, whereas the response of UE rises gradually by 6 dB/octave above 1.5 kHz. The sensitivities of the SSs at 1 kHz are between \(-44\) and \(-51\) dB [V/Pa]; those of the UEs at 1 kHz are between \(-44\) and \(-58\) dB [V/Pa]. Actually, DUE has a higher sensitivity at frequencies less than 1.2 kHz than both SS and UE. The frequency response of DUE resembles that of SS between 1.4 and 4 kHz and resembles that of UE at frequencies greater than 4 kHz. The sensitivity of DUE at 1 kHz is \(-41\) dB [V/Pa]. Figure 6 shows the frequency characteristics of SSP1 and SSP2. The frequency response of SSP2 rises gradually by 6 dB/octave between 0.4 and 4 kHz, except for peaks at approximately 0.9 and 2.8 kHz. By contrast, the frequency response of SSP1 is flat up to 10 kHz.
and is lower than that of SSP2 between 0.5 and 10 kHz. The sensitivities of SSP1 and SSP2 at 1 kHz are $-63$ and $-43$ dB [V/Pa], respectively.

5. Waveforms and spectrograms of NAM signals

The NAM signals were recorded simultaneously using two different types of NAM microphones: SS and DUE. The NAM microphones were attached to both sides of a speaker’s neck. The NAM signals were recorded with a 48-kHz sampling rate and 16-bit quantization. The signal duration was 4 s. Figure 7 shows waveforms and spectrograms of the NAM signals.

Several impulsive pop noises are overlapped with both NAM signals. The noises are generated by contact between the NAM microphone, which has a broad band spectrum, and the skin. Alternatively, they can result from a plosive of articulators, which has a narrow low-frequency spectrum. Plosives are shown for both NAM signals. Pop noises are overlapped in the NAM signal recorded by SS from 0 to 1 s, although they are less prominent in the NAM signal recorded by DUE. In the NAM signal recorded by SS, the formant pattern is clear at frequencies less than 3 kHz, but is only weakly observed above 3 kHz. The spectrogram of the NAM signal recorded by SS is limited to frequencies less than 3 kHz. In contrast, the formant pattern of the NAM signal recorded by DUE is clearly represented up to 6 kHz, although it is weak. The NAM signal recorded by DUE has a wider spectrum than that of SS. The frequency responses of both NAM microphones, as presented in Fig. 5, are well reflected in the spectrograms.

6. Conclusions

The frequency characteristics of five types of NAM microphone were measured. X-ray computed tomography scanning images of a soft-silicone-type NAM microphone and a urethane-elastomer-duplex-type NAM microphone show that the ECM is located at a very shallow position. The distance between the surface and the ECM diaphragm is between 1 and 2.5 mm.

The sensitivities of the soft-silicone-type, urethane-elastomer-type, and urethane-elastomer-duplex-type NAM microphones at 1 kHz are between $-41$ and $-58$ dB [V/Pa]. The sensitivities of the soft-silicone-type pseudo-NAM microphones at 1 kHz are between $-43$ and $-63$ dB [V/Pa]. In addition, the urethane-elastomer-duplex-type NAM microphone has the highest sensitivity among the measured NAM microphones. Results reveal that the frequency characteristics of each NAM microphone are similar, except for those of the soft-silicone-type pseudo-NAM microphones.

In a NAM signal recorded using the soft-silicone-type NAM microphone, formant patterns are clear at frequencies less than 3 kHz, but are only weakly observed above 3 kHz. In contrast, regarding the NAM signal recorded by the urethane-elastomer-duplex-type NAM microphone, formant patterns are clear at frequencies up to 6 kHz. The frequency responses of both NAM microphones are well reflected in the spectrograms.

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References