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Development of a wideband, wide-directivity ultrasonic speaker

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1. Introduction

We investigate the use of ultrasonic sensor to identify the positions and activities of people to enhance SECOM's indoor monitoring service for single occupants.

Ultrasonic indoor positioning systems that have been studied[1,2] have two disadvantages: They require multiple sensors to be installed indoors, and users must carry another device. To overcome these disadvantages, we developed a prototype system[4] consisting of a wide-directivity ultrasonic speaker[3], an array microphone, and a Frequency Modulated Continuous Wave (FMCW) signal processing unit. A single system can identify the positions and activities of people within 8-square meter room. Evaluation and verification of the prototype system revealed the following issues: (A) insufficient range resolution and (B) interference between multiple systems. The former is necessary to detect minute movements such as breathing, which is crucial for the monitoring service, and the latter hinders the installations of multiple systems to cover spaces larger than 8 square meters.

These issues are addressed in this study, and the technical details of the solution and the performance analysis are presented in this paper.

2. Method

The previous prototype system[4] used 25 kHz resonant narrowband ultrasonic transducers as the base sound source and 4 kHz (24 kHz to 28 kHz) bandwidth FMCW signal processing units, achieving a range resolution of 4.3 cm. In this study, we expanded the FMCW bandwidth of the prototype to address issue (A). Additionally, the wider bandwidth can be easily divided, which helps reduce interference between multiple sensors, thereby also resolving issue (B).

3. Design of wideband, wide-directivity ultrasonic speaker

We selected the wideband and narrow directivity ultrasonic speaker (KEMO L010), a commercially available small piezoelectric speaker, for its suitable features as the base sound source. The specifications of the L010 are illustrated in Fig. 1. Its frequency characteristics within a 10 dB range (21 kHz to 45 kHz) enable the radiation of wideband ultrasonic waves. On the other hand, the directivity angle (dashed lines) based on the half-width was narrow, approximately ± 25 degrees.

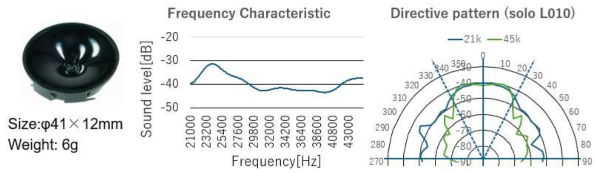

Fig. 1 Specifications of KEMO L010

The designs of the housing size and acoustic characteristics of the sensor structure must be altered due to the change in the base sound source.

3.1 Structural Design

The design guidelines to adhere to, as stated in the previous report[3], are as follows: I) the sound is transmitted from the base sound source to a thin duct tube, which acts as a waveguid, through an inverse exponential horn (Fig.2), II)12 ducts connected to the corresponding base sound sources are arranged in a circular ring shape, leading to the concentration of the sound in the center of the shape, and III) the focused sound is radiated from the central aperture.

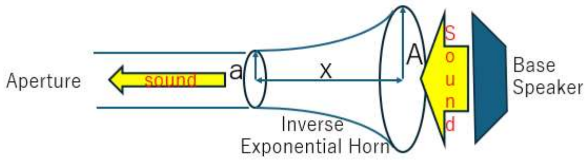

Fig. 2 Acoustic duct structure

The following two points were altered from the previous report[3] due to the expanded bandwidth from 4 kHz (24kHz to 28 kHz) to 24 kHz (21 kHz to 45 kHz).

1) Aperture radius: a

$$\lambda > 2\pi a \qquad (1)$$

where wavelength λ of the maximum frequency 45kHz, so a=1.2mm.

2) Inverse exponential horn length: x

$$A^2 = a^2 e^{mx} \qquad m = \frac{4\pi f_c}{c} \qquad (2)$$

where L010 radius A=20.5mm, cutoff frequency fc=21kHz, so x=7.3mm.

The blueprint of the final design of the wideband, wide-directivity ultrasonic speaker is shown in Fig. 3. The diameter and the thickness of the speaker were increased to 206 mm and 53 mm,

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respectively, as the diameter of the base sound source is increased from 16mm to 41 mm.

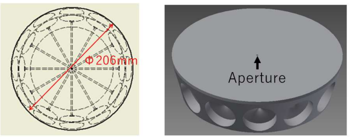

Fig. 3 Wideband, wide-directivity ultrasonic speaker (blueprint)

3.2 Weight reduction

Given the increased size of the speaker, using the same aluminum material for the housing as in the previous report would result in a weight of 5.8 kg, posing a significant risk of dropping. To reduce the weight, we switched the housing material to resin, and hollowed out the inside.

To identify the issues related to the change in materials, a preliminary experiment was conducted comparing the resin prototype (the same type mentioned in the previous report[3]), except for its material) with the one made of aluminum. The resin used was polylactic acid plastic (PLA), and the hollow was filled with a 15% fill rate.

The results of the experiment revealed that, unfortunately, the sound pressure level of the PLA housing was 9 dB lower than that of the aluminum housing, although the wide directivity of ±87 degrees was maintained. We speculate that the low sound pressure is due to sound leakage into the interior caused by the hollow structure and the resin remaining in the duct. We have selected the new design, prioritizing low weight.

Fig. 4 Appearance of wide-band, wide-directivity ultrasonic speaker (trial production)

Figure 4 shows the appearance of the wideband, wide-directivity ultrasonic speaker with a PLA housing. The PLA housing was covered with clay (white circles in Fig.4) to suppress sound leakage from the back of the base sound sources. 30g of clay was used for each sound source, which was the minimum amount to suppress sound leakage.

The total weight of the new speaker was 0.97kg, significantly lighter than the 5.8 kg aluminum housing speaker.

4. Result

The directivity and front sound pressure of the wideband, wide-directivity ultrasonic speaker proposed in this study were measured. The measurement system of the speaker employing Time Stretched Pulse (TSP) signals from 21 kHz to 45 kHz is shown in Fig. 5.

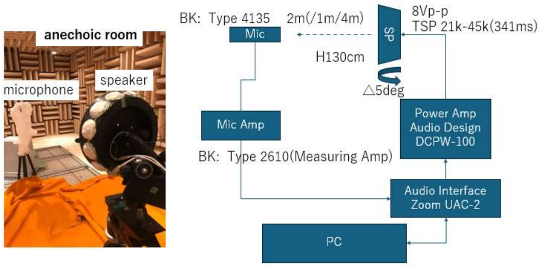

Fig. 5 Measurement system for performance evaluation of a proposed speaker

The speaker was vertically rotated from the floor in 5-degree increments, and the directivity was calculated every 1 kHz by frequency analysis.

Figure 6 shows the directivity pattern from 21

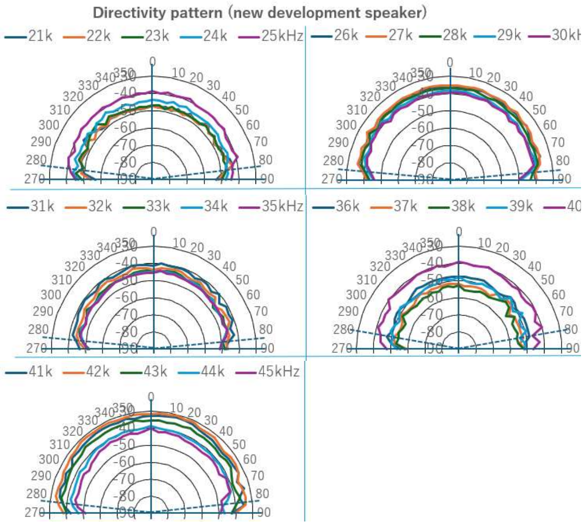

Fig.6 Directivity pattern of wideband, wide-directivity ultrasonic speaker

kHz to 45 kHz at a measurement distance of 2m, illustrating the directivity angles (dashed lines) approximately from ±80 to 85 degrees at all frequencies, indicating wideband and wide-directivity. The sound pressure level at 2 m in front of the speaker was 73 dB SPL.

5.Conclusion

To enhance SECOM's indoor monitoring service for single occupants to identify people's positions and activities, a wideband, wide-directivity ultrasonic speaker has been developed. Future studies include expanding the monitoring area, improving the accuracy, and increasing the sound pressure.

References

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