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A Narrow Pitch Matrix-Type MEMS Microphone Array for Acoustic Localization in Near-Field

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1. Introduction

Most studies of sound source localization using a microphone array have been conducted over large spaces on the metric scale[1,2], because of the limitations imposed by the wavelength of audible sound. Therefore, ultra-precise source localization in the near-field on the millimeter scale is challenging. However, if near-field positioning with high accuracy becomes possible, it will be useful for such applications as "high-precision positioning of objects with sound source markers attached" and " emitting sound localization of micro-insects". In addition, measurement of the sound field at narrow spacing will be useful for measurement of evanescent waves.

Therefore, we propose a high-precision sound source localization method that specializes in near-field measurements. We have constructed a system in which digital microphones are placed at narrow spacing, and the microphones are perfectly time-synchronized to each other without timing errors. The system also uses the pulse compression and a smaller microphone aperture, which is found in recent methods[3], to achieve highly accurate sound source localization.

2. Proposed methods

Fig. 1 shows a schematic view of the proposed method. Pulse compression is used to achieve high localization accuracy. The transmitted signal is a Manchester coded; M-sequence multiplied by a carrier wave. The frequency of the square (carrier) wave f_c is 6 kHz, the chip rate of the M-sequence signal is 6 kcps, the signal length is 2^{12}-1, and the number of repeats k is 8.

The receiver is equipped with a microphone array that consists of digital microphones (Infineon, IM69D120). The microphone has a built-in analog-to-digital converter (ADC) for the simplicity of the electronic circuit. The clock frequency of digital microphones f_m is 3.072 MHz. The microphone's clock was synchronized to achieve minimum timing error.

The signal obtained from the microphone is a digital signal called the pulse density modulation

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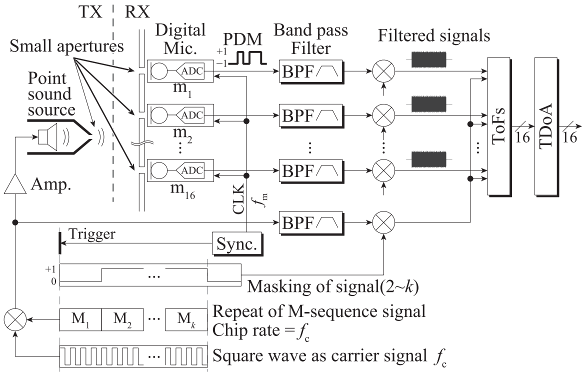

Fig. 1 Schematic view of TDoA based acoustic localization in near-field.

(PDM). Since it is difficult to handle, it is passed through a bandpass filter (BPF). The BPF has a bandwidth of 0.1 – 15 (kHz) and can remove offsets and high-frequency noise from the PDM signal. After passing through the BPF, the second and later cycles of the M-sequence are cut out by a multiplier to ensure the periodicity of the signal. The time of flight (ToF) was calculated by finding the lag at which the cross-correlation between TX and RX was maximized. The ToF was then converted to the time difference of arrival (TDoA) based on the microphone where the sound arrived earliest. When the measured TDoA is

$$r_{\mathrm{TDOA}} = [r_{\mathrm{TDOA},1}\, r_{\mathrm{TDOA},2} \cdots r_{\mathrm{TDOA},16}],$$

and the estimated TDoA at $P(x, y, z)$ is

$$p_{\mathrm{TDOA}} = [p_{\mathrm{TDOA},1}\, p_{\mathrm{TDOA},2} \cdots p_{\mathrm{TDOA},16}],$$

the estimated position, $P(x, y, z)$, is calculated to minimize the error $\sum(r_{\mathrm{TDOA}} - p_{\mathrm{TDOA}})^2$. For this calculation, the simplex method was used to obtain the optimal solution.

3. Experiment setup

Fig. 2 shows the experimental environment. We fabricated a speaker with $\emptyset$1.5 mm small aperture and used it as a sound source. This sound source is utilized as the approximation of a point source. It was confirmed in advance that the sound was emitted only from that aperture. The microphone array consists of 16 microphones arranged in a 4×4 matrix with 10 mm spacing, and the aperture diameter of the sound receiving holes is $\emptyset$0.8 mm. The distance between the microphone array and the

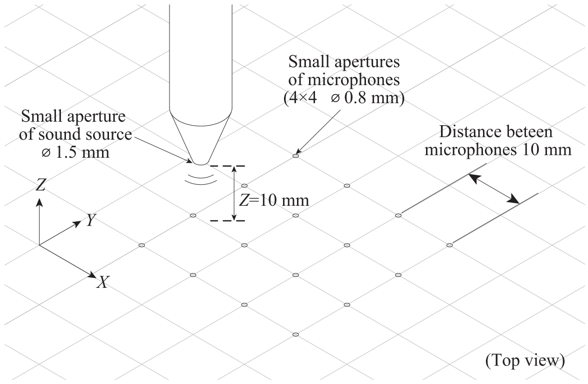

Fig. 2 Experimental environment. The plane of the microphone array is a wide flat surface. The experiment was carried out in an anechoic chamber.

point sound source was set to Z = 10 mm at all the measurement points. The plane of the microphone array was moved in the X-Y axes to each measurement point. A micro stage was used for precise movement in the X-Y axes. On the other hand, the Z axis direction was not moved, so the position was fixed. The experiment was conducted in a quiet anechoic chamber and the room temperature was kept at 25.5 – 26.5°C.

4. Results and discussion

Fig. 3 shows the results of the sound source localization. Twenty-five locations near the microphone array were used as evaluation locations. In all locations, the actual sound source position and the estimated sound source position are very close, with errors of less than 1 mm.

Fig. 4 shows the sound source localization errors at 25 locations. ΔX and ΔY both show the error from the actual position. The errors were biased like offset. If the offsets were adjusted, the accuracy would be about error < ±0.5 mm. In addition, the evaluation locations on the outer side of the microphones take points away from the point cloud.

In this experiment, only the X-Y direction was evaluated. In principle, the system is possible to localize not only in the X-Y direction but also in the Z direction. Also, the ToF and TDoA calculations are discrete, though interpolated calculations may further enhance the accuracy.

5. Conclusion

We proposed a near-field-specific source localization method using a MEMS microphone array with narrow spacing. We used a designed microphone array with low timing error, the TDoA method, and the pulse compression method to achieve highly accurate positioning. As a result, this method achieved highly accurate sound source localization with an error of less than 1 mm at all measurement points.

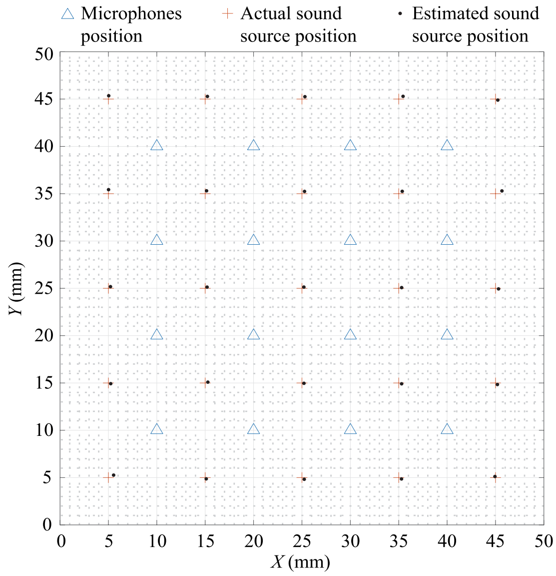

Fig. 3 Results of acoustic localization at each of 25 locations (Z = 10 mm).

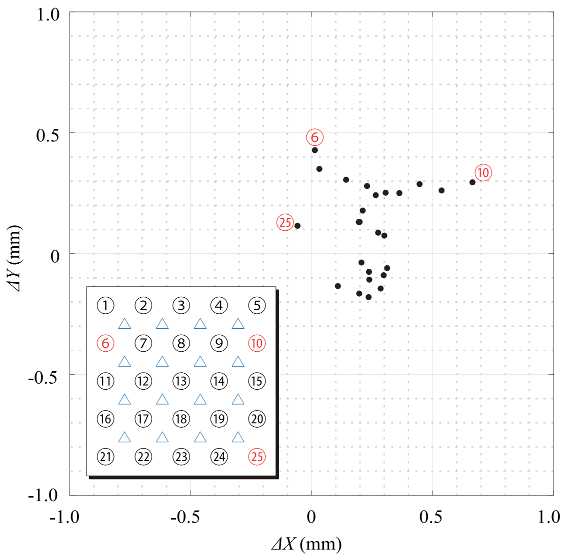

Fig. 4 Acoustic localization error of 25 locations. The number indicates the evaluation location.

Acknowledgment

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References

1. K. Zempo, K. Mizutani, and N. Wakatsuki, Jpn. J. Appl. Phys. 52 (2013) 07HG06.
2. H. Iwaya, K. Mizutani, T. Ebihara, and N. Wakatsuki, Jpn. J. Appl. Phys. 56 (2017) 07JC07.
3. L. Li et al., Meas. Sci. Technol., 32 (2021) p. 105106.