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Investigation of Ultrasonic Spatial Temperature Distribution Measuring Method with Concise Structure
簡略な構造による超音波空間温度分布測定法の検討

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1. Introduction

In terms of energy saving and environmental protection, non-contact measuring methods of spatial temperature distribution are required for suitable air-conditioning. As solutions, measuring methods for spatial temperature using acoustic wave are proposed[1, 2]. In conventional method using acoustic wave, it is necessary to install large-scale equipment in a measuring space. Meanwhile, portable measuring devices are also proposed.[3] However, only an average value of the spatial temperature on a propagation path of the acoustic wave could be measured using these devices.

In this study, a method for measuring the spatial temperature distribution using this portable measuring device is considered. And, results of experiments performed using proposed measuring device are described.

2. Theory of Temperature Measurement

The following equation for a sound wave is generally known.

$$\lambda = \frac{c}{f}. \tag{1}$$

Here, λ, f, and c represent wavelength [m], frequency [Hz], and velocity of sound [m/s], respectively. Meanwhile, the relationship between sound velocity c and temperature in Celsius t [°C] is expressed as the following equation:

$$c = 20.06\sqrt{273.15 + t}. \tag{2}$$

In the case of allocating an ultrasonic loudspeaker and two microphones as shown in **Fig. 1**, the ratio to the wavelength λ of the distance between two microphones ΔL ($\Delta L/\lambda$) is expressed as

$$\frac{\Delta L}{\lambda} = n + \frac{\Delta T}{T} = \frac{\Delta L \cdot f}{20.06\sqrt{273.15 + t}}. \tag{3}$$

Here, n represents the integer part of $\Delta L/\lambda$, and, ΔT, T, and $\Delta T/T$ represent the phase delay of MIC2 for MIC1 [s], the period of the sound wave [s], and the ratio of the phase difference ($0 \le \Delta T/T < 1$), respectively. From eq. (3), it is considered that the temperature can be determined from the phase delay ΔT.[3]

By using this measuring device, the average temperature on the propagation path of the ultra-

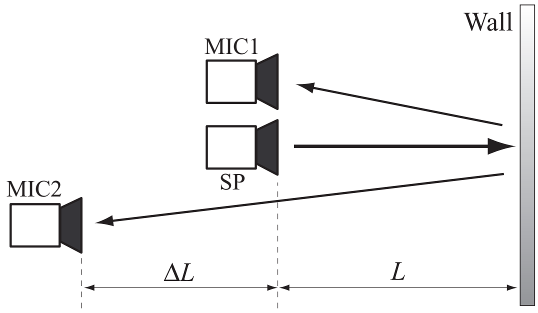

Fig. 1 Geometry of an ultrasonic loudspeaker and two ultrasonic microphones.

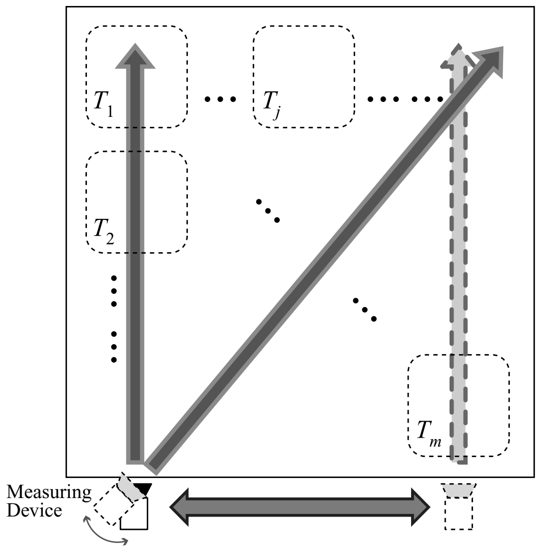

Fig. 2 Rotation and scanning of measuring device, and division of measuring space.

sonic wave is measured, and the spatial temperature distribution is derived by performing multiple measurements while changing the angle and position of the measuring device, as shown in **Fig. 2**.

Figure 2 also shows the measurement space divided into m regions. The temperature measured by the ultrasonic wave is considered to be the average value of the temperature of the regions that the wave is passed through, and the average temperature of the i-th propagation path t_i is represented by the following equation:

$$t_i = \frac{1}{L_i}\sum_{j=1}^{m} l_{i,j} T_j, L_i = \sum_{j=1}^{m} l_{i,j}. \tag{4}$$

Here, L_i, $l_{i,j}$, and T_j represent the length of the i-th propagation path, the length of the i-th propagation path that passes through the j-th region, and the

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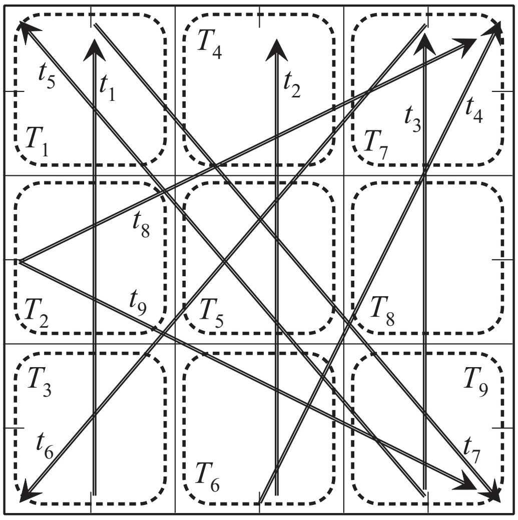

Fig. 3 Propagation paths of ultrasonic wave for measuring temperature distribution.

temperature of the j-th region, respectively.

The number of propagation paths that are required to derive the temperature of each region is m, which is equal to the number of regions. The average temperature of each propagation path is represented by the following equation:

$$\begin{bmatrix} L_1^{-1}\cdot l_{1,1} & L_1^{-1}\cdot l_{1,2} & \cdots & L_1^{-1}\cdot l_{1,m} \\ L_2^{-1}\cdot l_{2,1} & L_2^{-1}\cdot l_{2,2} & \cdots & L_2^{-1}\cdot l_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ L_m^{-1}\cdot l_{m,1} & L_m^{-1}\cdot l_{m,2} & \cdots & L_m^{-1}\cdot l_{m,m} \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_m \end{bmatrix} = \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_m \end{bmatrix}. \quad (5)$$

By solving eq. (5) for the temperature of the region T_j, the temperature can be derived for each region.

3. Experiments

The measurement space used in experiments is a space of 600×600 mm^2 surrounded by a wall. This space is divided into nine regions of 200×200 mm^2. Nine propagation paths of the ultrasonic wave are set, as shown in **Fig. 3**.

The phase delay of the output of MIC2 for that of MIC1, in the measuring device shown in Fig. 1, is measured, and is converted to the temperature. This measuring procedure is repeated for the number of the propagation paths. Using eq. (5), the temperature of each region is derived from the measured temperature on the propagation paths.

Measurement results are shown in **Fig. 4**. Figure 4(a) shows the derivation result of the temperature distribution of the measurement space without the heat source, and Fig. 4(b) shows the derivation result in the case which the heat source is installed to the region T_6. As the reference, measuring results by thermocouples are also shown in Fig. 4.

In Fig. 4(a), the maximum difference between

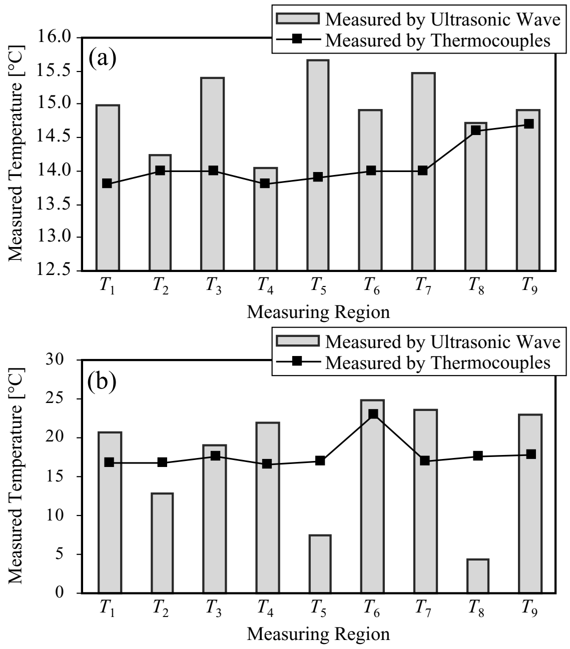

Fig. 4 Measuring result of temperature distribution; (a) without heat source, (b) with heat source in region T_6.

two measurements is 1.7 °C, and a conspicuous difference does not appear. However, in Fig. 4(b), there is the maximum difference of 13 °C between two measurements, and it is considered that an appropriate result is not obtained in the measurement using the ultrasonic wave. In the case which the heat source is installed in a region of the measuring space, the phase delay of the ultrasonic wave passing through this region may be violently fluctuated. Therefore, it is considered that a significant difference appears in the derivation results of the temperature distribution.

4. Summary

A method for measuring the spatial temperature distribution using the measuring device with concise structure is considered. If the temperature gradient exists in the measurement space, significant differences appear between the measuring results of temperature distribution by proposed device and that by the thermocouples. It is necessary to consider the technique to measure exact temperature distribution even in such conditions.

References

1. K. Kudo, K. Mizutani, T. Akagami, and R. Murayama: Jpn. J. Appl. Phys. **42** (2003) 3189.
2. I. Saito, K. Mizutani, N. Wakatsuki, and S. Kawabe: Jpn. J. Appl. Phys. **48** (2009) 07GB05.
3. H. Masuyama and R. Umetani: Proc. Symp. Ultrason. Electron. (2011) p.191.