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# Investigation of Ultrasonic Spatial Temperature Measuring Device with Concise Structure
# 簡略な構造をもつ超音波空間温度測定装置の検討

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## 1. Introduction

In recent years, in terms of energy saving and environmental protection, non-contact measuring of spatial temperature distribution are required for suitable air-conditioning. As a solution, a method for measuring spatial temperature using acoustic wave is proposed.[1,2] In conventional spatial temperature measuring method using acoustic wave, it is necessary to install large-scale equipment in a measuring space. In addition, a portable measuring device is proposed,[3] it requires a high-precision feed mechanism in mechanical parts.

In this study, a technique to simplify the mechanism in the portable temperature measuring device is considered. Then, results of experiments performed using proposed measuring device are described. The range of measurement of the device examined in this study is approximately set from 10[°C] to 25[°C]. This range is assumed to air-conditioned office space. And, the objective of the accuracy of the measurement is set in ± 1[°C], considering the temperature sensitivity of human.

## 2. Theory of Temperature Measurement

The following equation for a sound wave is generally known.

$$\lambda = \frac{c}{f}. \quad (1)$$

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:

$$c = 20.06\sqrt{273.15 + t}. \quad (2)$$

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 $\Delta L$ is expressed as

$$\frac{\Delta L}{\lambda} = \frac{\Delta L \cdot f}{20.06\sqrt{273.15 + t}}. \quad (3)$$

In eq. (3), by replacing the integer part of $\Delta L/\lambda$ as *n*, eq. (4) is obtained.

$$n + \frac{\Delta T}{T} = \frac{\Delta L \cdot f}{20.06\sqrt{273.15 + t}}. \quad (4)$$

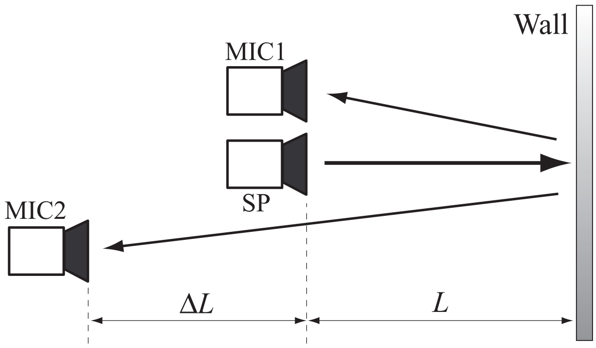


Fig. 1 Geometry of an ultrasonic loudspeaker and two ultrasonic microphones.

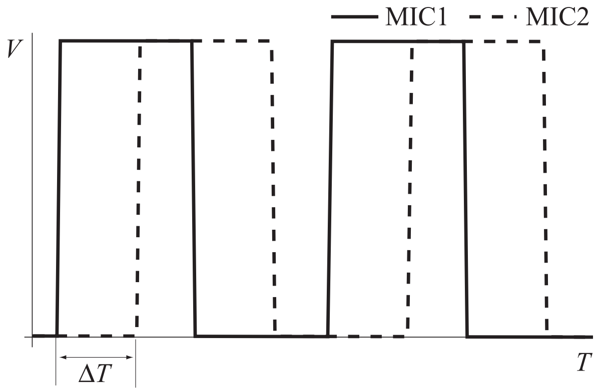


Fig. 2 Phase delay $\Delta T$ between two microphones.

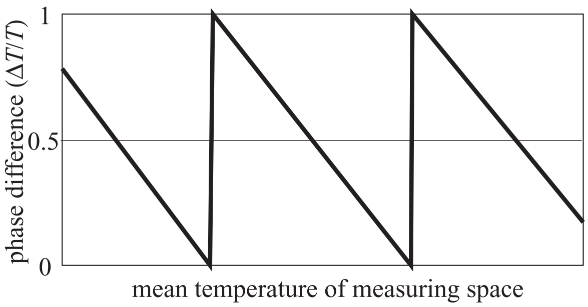


Fig. 3 Expected relationship between temperature of measuring space and phase difference $\Delta T/T$.

Here, $\Delta T$, $T$, and $\Delta T/T$ represent the phase delay of MIC2 for MIC1, the period of the sound wave, and the ratio of the phase difference ($0 \leq \Delta T/T < 1$), respectively. In eq. (4), the relationship between $\Delta T/T$ and *t* is considered as shown in Fig. 3. From Fig. 3, it is considered that the ratio of phase difference repeats the linearly change in a certain range of the

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temperature. When the relationship between the temperature and the phase delay is linearly approximated in each range of the temperature, it is considered that the both have a proportional relationship in this region, and a linear equation for this region can be obtained. Therefore, when the measuring range of the temperature is known, it is considered that the temperature can be determined from the phase delay, by using single or multiple linear equations corresponding to the measuring range.

## 3. Experiments

An ultrasonic loudspeaker (Nippon Ceramic T40-16) and two ultrasonic microphones (Nippon Ceramic R40-16) are allocated as shown in Fig. 1. The value of $\Delta L$ and $L$ are set to 250 [mm] and 500[mm], and the center frequency of the ultrasonic wave is 40.3 [kHz]. The output of each microphone obtained by transmitting and receiving of the ultrasonic wave is measured with an oscilloscope after amplification. Then, by measuring the phase delay of the output waveform of MIC2 for that of MIC1, the temperature of the measuring space is obtained. In this experiment, the temperature measured by an alcohol thermometer is used for the reference.

Figure 4 shows the results of the spatial temperature measured by the proposed measuring device. In Fig. 4, the temperature measured by the alcohol thermometer is indicated by the $x$-axis, and the temperature measured by the proposed device is indicated by $y$-axis. Measurement experiments are performed 120 times, and then, the temperature measured with the alcohol thermometer is from 11.0 [°C] to 17.2 [°C].

Figure 5 shows a distribution of the differences of measured temperature between the alcohol thermometer and the proposed measuring device.

In this experiment, both of the alcohol thermometer and the proposed device are measure same subject. Therefore, the slope of the regression line is 1, and the intercept of that is zero, theoretically. From Fig. 4, considering the intercept of the regression line of slope 1, and its value is 0.008. In addition, From Fig. 5, the range of the difference in measuring value between the proposed device and the alcohol thermometer is from -0.5[°C] to 0.7 [°C]. In this experiment, since the objective of measuring accuracy is set within ± 1 [°C], it is considered that this value of intercept is small enough to be a difference between two measurements. Therefore, in the range of the temperature set in this experiment, it is considered that the proposed device is possible to measure the temperature.

## 4. Summary

In this study, the technique to simplify the portable spatial temperature measuring device is considered. Measurement is carried out using the phase difference between the outputs of two microphones set in a different position. Experimental results show that the temperature of the measurement space can be measured accurately using proposed device, though the range of the temperature is narrower than the objective of that.

It is necessary to understand the range of temperature measurements while keeping the accuracy, and to determine the optimal distance between microphones, and these will be examined as the future work.

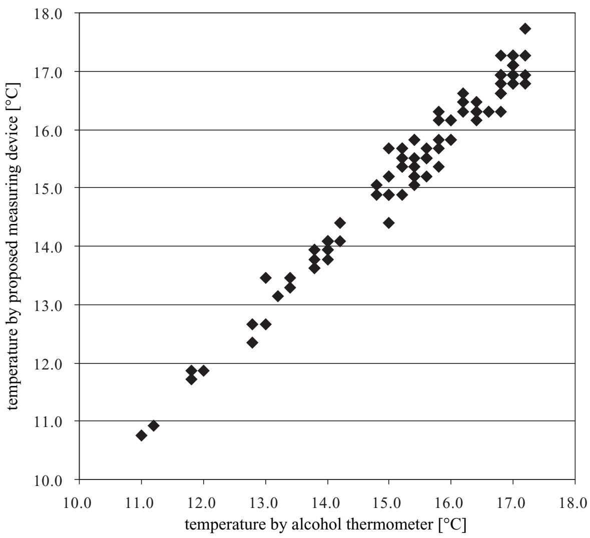


Fig. 4 Measuring results of spatial temperature: measured by alcohol thermometer ($x$-axis) versus proposed measuring device ($y$-axis).

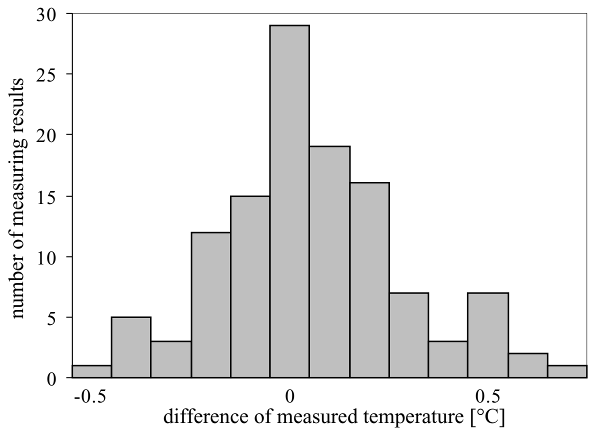


Fig. 5 Distribution of differences of measured temperature by two measuring method.

### References


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