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Measurement of mist density using airborne ultrasound
ミスト濃度の空中超音波による計測の試み

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1. Introduction

The evaporative fog cooling system is widely used among several cooling systems for greenhouse culture[1]. It decreases the temperture in the greenhouse by vaporization heat of sprayed mist. Spraying is controlled by the thermometer and the timer. However, there is a limit of the mass of water that can evaporate into the air depends on the temperture and the relative humidity, and excessive spraying may cause problems like damaged leaves of crops. If measurement of the mist density is realized, it will contribute to the more effective control of spraying.

Measurement of the mist by optical method is achieved in an earlier study[2]. According to this study, logarithms of light transmission rates to the mist are inversely proportional to the mist density in the optical path. However, optical probes are also sensitive to the light other than explicit light source. Therefore, it is difficult to use the optical probes outdoors. Sound probes are commonly applied to measure temperature[3,4] and wind parameters[5]. They can also detect the existence of mist[6]. However, they have not yet led to a quantitative measurement of mist.

In this paper, the effect of mist density on the attenuation of the sound pressure level is described. In this experiment, an optical probe measured the change of the mist density to be related with the attenuation of the sound pressure. Correlation between the attenuation of the sound pressure and the mist density was examined by the experiment with an ultrasonic probe using airborne ultrasound.

2. Principle

Figure 1 shows a schematic diagram of a sound probe and a quadrature detector. The sound probe consists of an ultrasound speaker (SP), a microphone (MIC) and a propagation path. $T(t)=\sin 2\pi ft$ is a transmitted signal. A received signal reflecting the state of the propagation path is expressed as

$$R(t) = \alpha \sin(2\pi ft - \theta)\,, \tag{1}$$

where, α is an amplitude attenuation and θ is a phase delay. They are obtained using quadrature detection. As a transfer function on the propagation path, a complex amplitude V is shown as

$$V = V_{\mathrm{Re}} + iV_{\mathrm{Im}}\,, \tag{2}$$

where V_{Re} and V_{Im} are the complex components of real and imaginary parts. Amplitude characteristics $|V|$ and phase characteristics θ are shown as

$$|V| = \sqrt{V_{\mathrm{Re}}^2 + V_{\mathrm{Im}}^2}\,, \tag{3}$$

$$\theta = \tan^{-1}\frac{V_{\mathrm{Im}}}{V_{\mathrm{Re}}}\,. \tag{4}$$

The effects of the mist on acoustical characteristics are measured by acquiring $|V|$ and θ where mist exists along the propagation path or not.

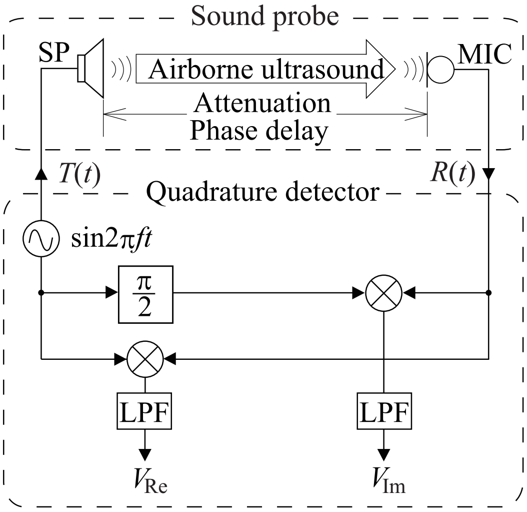

Fig. 1 Schematic diagram of a sound probe and a quadrature detector.

3. Experiment and results

Figure 2 shows the experimental environment. The ultrasonic probe consists of ultrasonic transducers (PT40-16 and PR40-16/Nippon Ceramic) and a propagation path. The transducers were placed face-to-face at 150 mm height and 150 mm apart in the case. An infrared LED and a photodiode device (TLN110 and TPS611F/Toshiba) were placed close to the propagation path of the ultrasonic probe.

The experiment was carried out for 3 min. The case was preliminarily filled with mist from an

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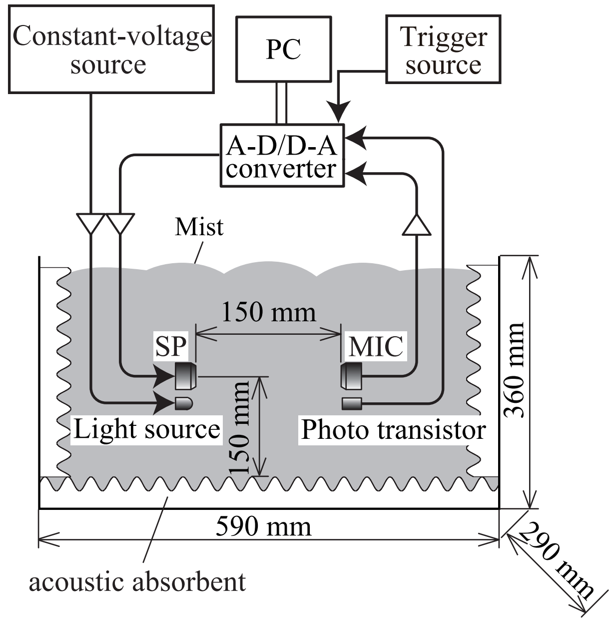

Fig. 2 Experiment environment of an ultrasonic probe using airborne ultrasound and an optical probe.

ultrasonic humidifier to stabilize mist density. $|V|$, θ and the light transmission rate to decreasing mist were measured by the ultrasonic probe and the optical probe. The transmitted signal was a 40 kHz burst wave. The sampling frequency, the sampling duration and the measurement frequency were 200 kHz, 0.02 s and 2 Hz.

Figure 3 shows the experimental result. The ultrasonic transmission rate and light transmission rate are shown in dB. Before the experiment, we measured the acoustical signal amplitude and the light intensity without mist for 1 minute and set the obtained value as 0 dB. The change of the ultrasonic transmission rate to mist approximately agrees with that of the light transmission rate. There is a slight difference between them. It seems to be caused by the differences of the propagation paths of ultrasound and light.

Figure 4 shows the correlation between the ultrasonic transmission rate and the light transmission rate. The regression line and the coefficient of determination (R^2) are also shown in Fig. 4. The value of R^2 (=0.9884) shows that the ultrasonic transmission rate are strongly correlated with the light transmission rate. Therefore, the obtained results suggest that the change of the attenuation of the sound pressure is caused by the changes of the mist density. The changes of the sound velocity were also measured. However, there was no correlation between the sound velocity and the mist density. This means that the mist density simultaneously measured from ultrasonic attenuation while the temperature and the wind velocity are measured from sound velocity.

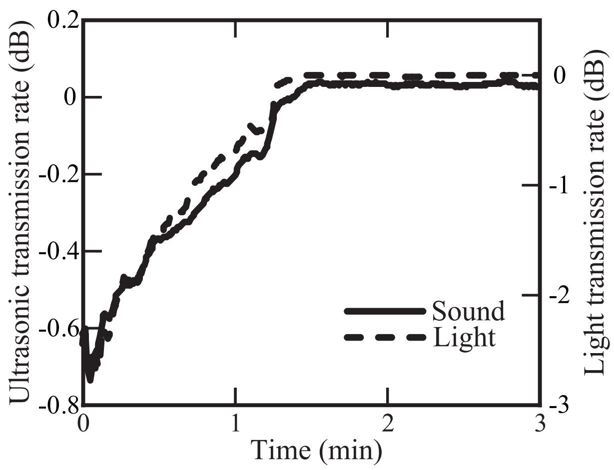

Fig. 3 Experimental result.

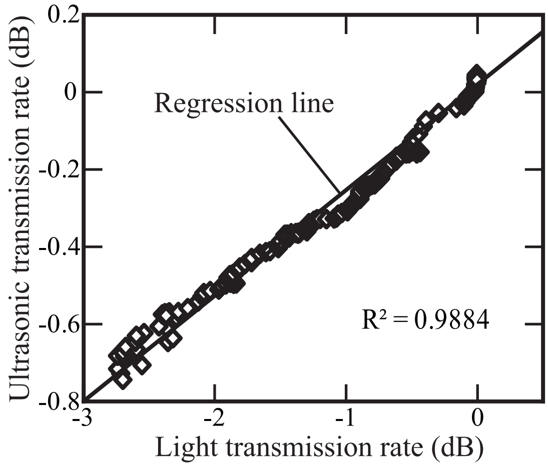

Fig. 4 Correlation between ultrasonic transmission rate and light transmission rate.

4. Conclusion

The effect of the mist density on the attenuation of the sound pressure was confirmed experimentally. This acoustical method using airborne ultrasound was found to be effective for the measurement of the mist density.

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