Ultrasonic Anemometer Using Sound Reflection on Wall
壁面反射を用いる超音波風向風速計

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1. Introduction

It is necessary to keep temperature adequately for making comfortable work conditions of living spaces and factories1, 2). However, convection arise when temperature distribution exist in the spaces. And convection plays a role in heat exchange. Therefore, convection is important parameters for the temperature management of all spaces. Sound probes are very favorable for getting these parameters along sound paths by exploiting non-contact and area measurements3, 4).

In this paper, we describe ultrasonic anemometer using sound reflection on wall. Before, we proposed an ultrasonic anemometer using acoustic reflector5, 6). However, it is considered to use a wall of the measurement object space if measurements are carried out indoor. And so, wind parameters were measured to change distance of acoustic sensors from a wall and verified practical effectiveness of measurements using a wall.

2. Principle

Figure.1 shows a schematic diagram of the proposed measurement system using sound reflection on wall. This ultrasonic anemometer forms a shape of isosceles triangle and consists of loudspeaker (SP), microphone (MIC) and wall. A wind-velocity vector, \( \mathbf{w} \) is decomposed to its \( x \)- and \( y \)-components, \( w_x \) and \( w_y \) in the coordinates along the direct sound, and \( \mathbf{w} \) is also decomposed into its \( x' \)- and \( y' \)-components, \( w'_x \) and \( w'_y \) in the coordinates along the reflected sound. The time of flight (TOF) of SP1-MIC1, \( t_{d1} \) (s), the TOF of SP2-MIC2, \( t_{d2} \) (s), the TOF of SP1-wall-MIC1, \( t_{r1} \) (s), the TOF of SP2-wall-MIC2, \( t_{r2} \) (s), and the sound velocity, \( c \) (m/s), are expressed as:

\[
\begin{align*}
    t_{d1} &= \frac{L_1}{c \cos \phi + w_x}, \\
    t_{d2} &= \frac{L_1}{c \cos \phi - w_x}, \\
    t_{r1} &= \frac{L_2}{c \cos \phi + w_y}, \\
    t_{r2} &= \frac{L_2}{c \cos \phi - w_y},
\end{align*}
\]

\[
\begin{align*}
    w_x &= \left( \frac{1}{t_{d2}} - \frac{1}{t_{d1}} \right), \\
    w_y &= \frac{1}{t_{d2}} - \frac{1}{t_{d1}}.
\end{align*}
\]

Fig. 1 Principle of an ultrasonic anemometer using sound reflection on wall and the coordinate system.

\[
\begin{align*}
    t_{r1} &= t_{r11} + t_{r12} = \frac{L_2}{c \cos \phi + w_x} + \frac{L_2}{c \cos \phi + w_y}, \\
    t_{r2} &= t_{r21} + t_{r22} = \frac{L_2}{c \cos \phi - w_y} + \frac{L_2}{c \cos \phi - w_y},
\end{align*}
\]

where \( L_1 \) (m) denotes the distance of the direct path and, \( L_2 \) (m) denotes the each distance divided the reflected path. \( \phi \) denotes the angle bended by wind. \( w_x \) is straightforwardly calculated by using eqs. (1) and (2) from following an equation:

\[
\begin{align*}
    w_x &= \left( \frac{1}{t_{d2}} - \frac{1}{t_{d1}} \right),
\end{align*}
\]

\[
\begin{align*}
    \theta &= \tan \left( \frac{w_y}{w_x} \right),
\end{align*}
\]

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3. Experiment

Figure 2 shows a schematic diagram of experimental setup. Experiments are carried out in a wind tunnel. A proposed anemometer is formed with a shape of isosceles triangle. A probing signal is generated by a PC (Pentium III 750 MHz, 256 MB-RAM) and transmitted from the SP (SD9D4B/Clarion) by way of an amplifier and a D-A converter (DAQCard-6062E/National Instruments). The direct wave and the reflected waves are received by MIC (CMS-64/Bousung Electron) and stored in the PC by way of an amplifier and an A-D converter (DAQCard-6062E/NI). The sampling frequency is 250 kHz and a probing signal is the burst wave of $5.0 \pm 2.5$ kHz with ten wavelengths. TOFs are determined as average of ten measurements and from the cross correlation of the transmitted and received signals. Chirp signals are used for improving the accuracy of the TOFs measurements. The experimental measurements are performed at $l = 0, 1.0$ and $2.0$ (m) under wind velocity is 5.0 m/s every 30 s for twenty minutes.

In this experiment, four conventional ultrasonic anemometers (81000/Young) were used for reference wind velocity and direction. Figure 3 shows the differences between the measured wind velocity and references. $w_r$ and $w_r$ denote measured and references wind velocities. Figure 4 shows the differences between the measured wind direction and references. $\theta_r$ and $\theta_r$ denote measured and references wind directions.

4. Conclusion

In this paper, wind velocity and direction were measured by an ultrasonic anemometer using sound reflection on wall. The measurement ability and the accuracy are successfully confirmed. Measuring results obtained by this proposed anemometer and conventional anemometers agree with each other considering the difference between area and point measurements. The proposed anemometer can measure wind velocities and directions by use of sound reflection on wall of offices, green houses used in agricultural fields.

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References