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Two-dimensional ultrasonic anemometer using the directivity angle of an ultrasonic sensor

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Abstract

There has been continuous research on the ultrasonic sensors [L.C. Lynnworth, Y. Liu, Ultasonic flowmeters: half-century progress report 1955–2005, Ultrasonics (2006) 1371–1378]. This study used the directivity characteristic based on phase measurement, which ultrasonic sensor has. Transmitter has wide directivity, and in its range of directivity, receivers are located to measure wind direction and velocity. The velocity experiments which are the result of this production system indicate that the system error rate is 2%. The wind direction measurements also give the same result, an error of ±3°. This result is similar to existing anemometers. However, this new anemometer could possibly have a much higher sampling rate, operating circuit and system structure, which could be much simpler than the previous anemometer.

Keywords: Ultrasonic; Anemometer; Directivity angle; 2D

1. Introduction

Wind measurement is an important factor for detecting natural phenomena in various industrial fields. Wind measurement can be applied not only to industrial fields but also to environmental monitoring and controlling systems, indoor air conditioning systems, the weather forecasting systems and so on. To improve problems with the previous mechanical sensors, methods that use MEMS-type sensors or ultrasonic sensors [1–3] have been studied. A MEMS-type sensor is a contact type so that the abrasion property is high. It is sensitive to dust, and it is difficult to use for a 2D anemometer in the atmosphere [4]. A method to use ultrasonic sensors is being studied and developed because this method has a distinguished advantage over the non-contact type [1]. For measuring wind velocity using an ultrasonic sensor, there are two methods: transit-time measurement and vortex measurement [5–7]. With vortex measurement it is difficult to measure wind direction. So the method of transit-time measurement is used to measure wind velocity and direction [8].

This study is based on the method of transit-time measurement and a variation of transit time is measured by a phase shift [8]. This study uses a directivity angle which is one of the characteristics of an ultrasonic sensor and, therefore, does not use a time-sharing method. By using the method of transit-time measurement, this study can realize a high sampling rate despite having a simple structure and low costs.

2. Principle

All methods of 2D ultrasonic anemometers use a transceiver and time-sharing method to measure wind direction. If an ultrasonic anemometer uses a time-sharing method, the sampling rate will be lower and the inner structure will be more complicated. To alleviate the problems of the time-sharing method, this study suggests the system composition that is shown in Fig. 1. All receivers can receive ultrasonic signals simultaneously by a single transmission as shown in Fig. 1. In this structure, a time control signal is not required in the transmitting circuit, so the entire structure is simpler than the previous ones.

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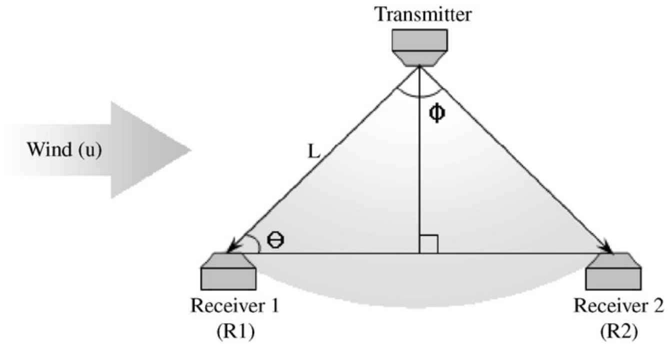

Fig. 1. Schematic of ultrasonic anemometer using the directivity angle of an ultrasonic sensor. Here, L is the length of the ultrasonic path, θ is an angle between the ultrasonic path and the bottom plate and φ is the directivity angle of the transmitter.

2.1. Measuring wind velocity

So far, the measurement of flow velocity using an ultrasonic sensor is calculated by measuring the transit time of ultrasonic signals between the transmitter and receiver, which are located on opposite sites. However, the proposed system uses the directivity angle of an ultrasonic sensor as shown in Fig. 1. Receivers are located on the same axis and they have the same L and θ. The proposed system does not need to use a time-sharing method, because all receivers can receive ultrasonic signals simultaneously by a single transmission.

In this study, a method of measuring wind velocity is developed by using a phase shift based on measuring the transit time of ultrasonic signals. The delay time, variation of transit time of ultrasonic signals by the wind is measured by measuring the phase shift of the receiving signals. This principle is represented in Eq. (1) [8]

$$t = t' + \Delta t. \tag{1}$$

Here, t is the transit time, t' is the transit time of the ultrasonic signals when there is no wind, and Δt is the phase shift.

If the ultrasonic path is far away, measuring the delay time can be done easily through the variation of transit time. But, if the ultrasonic path is close, measuring the delay time through the phase shift is more efficient than if the path is far away, because the variation of transit time is too small.

The equation to calculate the wind velocity using the proposed principle is represented in Eq. (2) [3,5,8]. This equation is applied to an ultrasonic anemometer also using time-sharing method

$$t_{R1} = \frac{L}{v - u\cos\theta}, \tag{2.1}$$

$$t_{R2} = \frac{L}{v + u\cos\theta}, \tag{2.2}$$

$$u = \frac{L}{2\cos\theta}\left(\frac{1}{t_{R1}} - \frac{1}{t_{R2}}\right). \tag{2.3}$$

Here, t is the ultrasonic travel time of each path, v is the ultrasonic velocity and u is the wind velocity.

Previous systems using the time-sharing method were not affected by the temperature of the wind when applying Eqs. (2) and (3) and this removed the v factor which is sensitive to temperature [8,9]. However, in this proposed system, the transit time of the ultrasonic signals is not measured when there is no wind. Therefore, this study calibrates when the wind velocity is calculated with a temperature sensor. Fig. 2 is the result of calculating the change of delay time by temperature in the designed system. The variation is small in the low wind velocity. However, the change is huge in the case of high wind velocity, and hence compensation is required.

2.2. Measuring wind direction

The proposed system locates two receivers on X- and Y-axis for measuring wind direction and velocity about X and Y directions. The wind direction is calculated by adding a vector that is the velocity factor on each axis [5]. Direction is calculated by the following equation when the velocity of direction is decided by the receivers which are located in the directivity angle of the ultrasonic sensor:

$$\theta = \arctan\frac{u_y}{u_x}. \tag{3}$$

Here, u_x and u_y represent direction velocity along the X- and Y-axis.

The 2D can be calculated as a result of wind direction, because in the space where the wind passes, there is no disturbance factor.

3. System composition

The entire system is composed as shown in Fig. 3. The transmitter (Tr) is connected with the oscillated circuit at

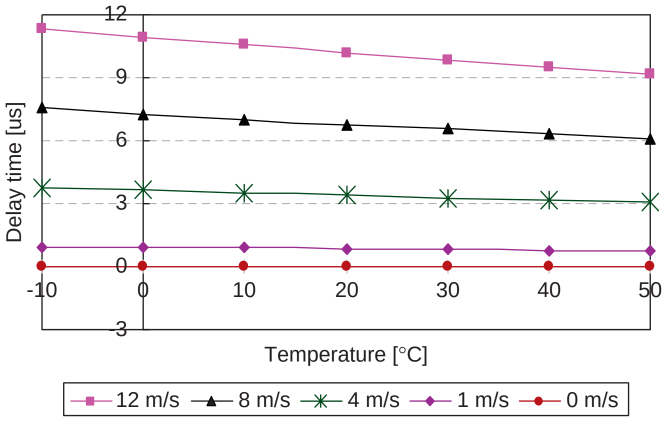

Fig. 2. The computation graph of the delay time according to the wind temperature.