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Anemometer Using Long Baseline Acoustic Probe with Precise Wireless Trigger

高精度な無線トリガによる長基線音響波プローブを用いる風速計

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1. Introduction

Acoustic probes were suggested to sensing various parameters along a baseline without contact[1,2]. The authors also suggested an acoustic probe having a long baseline for monitoring micrometeorology such as temperature and wind velocity[3]. The probe was applied to a sensing grid system for air temperature distribution. That system had several network-controlled sensor nodes which wirelessly communicate with each other[4,5]. In primarily proposed system, although control signals are transmitted by wireless, a coaxial cable is used for a trigger line because of the requirement of strict synchronization among sensor nodes. In temperature measurements, the synchronization of the start of measurement at each sensor node was not strictly important because of the error compensation by round trip measurement. Thus, the strict triggering could be omitted in such a system[6]. In the case of wind velocity measurements, the synchronization primarily determines the measurement accuracy. Therefore, a precise wireless triggering has been desired for wireless sensing grid system.

In this work, a precise wireless triggering system for anemometers using acoustic probes having long baseline is proposed. Its principle of this triggering system is described and the performance is experimentally evaluated. Using the proposed triggering system largely contributes to achieving large-scale wireless sensing grid systems using long baseline acoustic probes.

2. Operation Scheme of Wireless Triggering

A one way acoustic probe basically has a loudspeaker (SP), a microphone (MIC), and a sound path. Usual acoustic probe for round trip measurement has a pair of one way acoustic probes. The acoustic probe measures time of flights (TOFs) of a sound wave by cross-correlation method using chirp signals. It is desirable that the sound transmission and reception start at the same time in usual case. The triggering system here using a radio wave

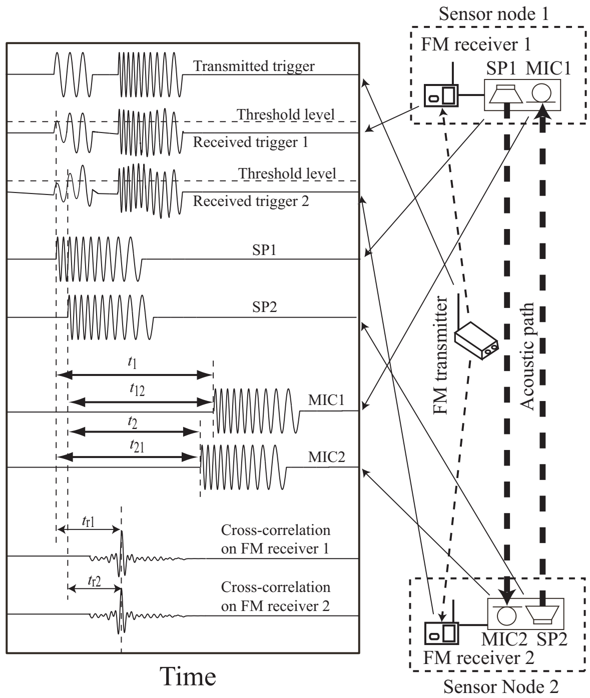

Fig.1 Wireless triggering system

frequency modulated with the trigger signal. If a rectangular pulse is used for a trigger signal in the same way as wired trigger line, the synchronization fluctuates in the order of ms due to unstabilities in received signal for commercially available FM receivers. This causes the errors of 10 m/s order in the wind velocity measured by an acoustic probe having a baseline of several tens meters.

The same scheme as TOF measurement is also useful for the trigger signal in radio wave. That is to say, the measurement starts at each sensor node roughly in usual way using threshold crossing of the trigger signal, and then the synchronization errors caused by the unstability can be corrected by cross-correlation method using chirp signals for the trigger signal in the radio wave. The triggering system is illustrated in **Fig. 1**. The operation consists of following steps.

1. FM transmitter sends a trigger signal to FM receivers. The signal contains a sine burst signal followed by a chirp signal for error correction.
2. Each FM receiver outputs the received signal to a

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trigger input at the sensor node.

3. Each sensor node starts sound transmission and sound acquisition by the sine burst part of the trigger signal. The received trigger signal is also acquired. The delay times from the sound transmission to the sound reception observed at node 1 and node 2 are t_1 and t_2, respectively.
4. The starting times of the chirp signals in the trigger signals at the sensor nodes 1 and 2, t_{r1} and t_{r2}, are measured by cross-correlation method using the chirp signal part of transmitted trigger signal and the received ones. The synchronization error is given by $t_{err} = t_{r1} - t_{r2}$.
5. The delay times t_1 and t_2 also contain $-t_{err}$ and t_{err}, respectively. Therefore, actual TOFs are obtained by $t_{12} = t_1 - t_{err}$ and $t_{21} = t_2 + t_{err}$.

3. Experimental Verification

The wireless triggering system is implemented and experimentally evaluated. An experimental sensor node consists of a loudspeaker, a microphone, a personal computer (PC), an analog to digital and digital to analog converter (A-D/D-A), a wireless LAN tranceiver, and an FM receiver. The whole measurement system consists of two sensor nodes, a wireless LAN access point, an FM transmitter, an A-D/D-A converter, and personal computer for controlling the sensor nodes. Each PC communicates with each other entirely by wireless.

The experiment was performed outside at a field in the Terrestrial Environment Research Center, University of Tsukuba. The sound path has a length of 40m. Wind velocity along the sound path was measured using this system and during an hour and compared with the values measured using commercially available ultrasonic anemometers. This anemometer measures three-axial components of wind velocity. In this experiment, the component along the baseline of the acoustic probe is only considered. Since the proposed system indicates a wind velocity that is spatially averaged along the sound path, the mean value by four anemometers regularly arranged along the sound path is used for a reference. Wind velocity along the sound path is repeatedly measured at 10 s interval for 600 s.

The result is shown in **Fig. 2**. Black triangular symbols and white circular symbols denote the wind velocities measured by the acoustic probe with threshold based triggering and with the proposed triggering, respectively. The solid line denotes the reference wind velocity, which is mean value from four reference anemometers. The wind velocity measured using acoustic probe fluctuates up to ±4 m/s with threshold based triggering. This shows the unstabilities in the trigger signal by means of the FM radio wave. The time fluctuation reached up to about 1.4 ms in this evaluation. In contrast, the measured value with corrected trigger is quite stable and well agrees with the reference value. The difference between the proposed and the reference was within ±0.3 m/s, which shows the triggering error is within 0.1 ms. This is less than one tenth of the threshold based triggering.

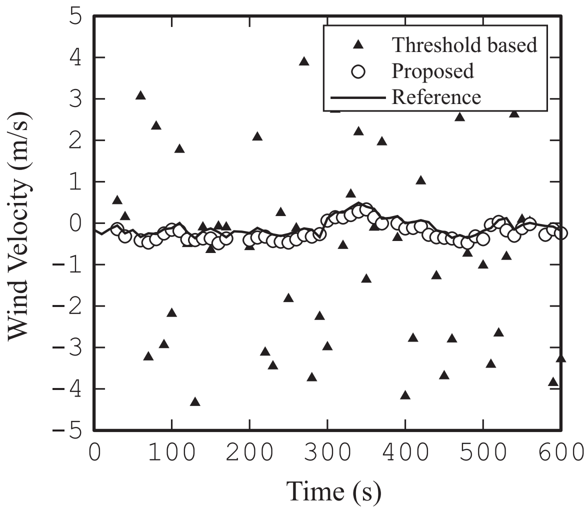

Fig. 2 Comparison between the proposed system and the reference from four anemometers.

4. Conclusions

A precise wireless trigger system using the cross-correlation method for a trigger signal is proposed and the performance of an anemometer having an acoustic probe using the proposed wireless trigger is evaluated. The proposed triggering system improved the measurement accuracy up to about ten times compared to the system using the threshold based triggering. This contributes to achieving a wireless sensing grid system of large scale such as a micrometeorology monitoring system.

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