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Wireless Sensor for Temperature with Asynchronous-Type Ultrasonic Probe

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1. Introduction

Acoustic probes have been proposed for non-contact sensing of various phenomena such as air temperature, humidity, and wind velocity. However, existing acoustic probes are costly to develop and not suitable for expanding in large numbers. This is because they require complex hardware with high real-time performance. In this paper, we propose an asynchronous acoustic probe using single board computers (SBCs) which is easy to develop and suitable for expansion.

Table 1 shows a comparison among existing and proposed acoustic probes. The acoustic probes can be roughly categorized into two types: (wired/wireless) and (synchronous/asynchronous). As summarized in the table, wireless asynchronous probe with wind resistance does not available. This is because it assumes that ToFs (Time-of-Flight) of going and returning acoustic waves are the same. Furthermore, existing acoustic probes require complex hardware since they assume that there is no hardware latency. Although commercial small devices with audio interface, such as single board computers, have signal processing capability to build acoustic probes, the existence of random latency at audio interface becomes a barrier to achieve simple acoustic probes.
The purpose of this study is to propose wireless and asynchronous acoustic probe using single board computer with audio latency, by devising wireless triggering that can cancel the effect of audio latency. Different from the previous study[4], the proposed probe can operate even in windy.

2. Principle of Temperature Measurement

Acoustic probes basically consist of speaker (SP), microphone (MIC) and an acoustic path. The air temperature T (°C) is calculated as

$$T = (c - 331.45)/0.607, \quad (1)$$

where c (m/s) represents the sound velocity,

$$c = L/t, \quad (2)$$

and L and t represent the length of the acoustic path and the ToF of the acoustic wave, respectively.

Figure 1 shows the proposed acoustic probe. The proposed probe consists of a controller and two transceivers. The proposed probe measures ToF while canceling the effect of random latency as follows.

Table 1 Previous research and our system

	Wired/ Wireless	Sync/ Async	under wind	trigger media	Audio latency
[1]	Wired	Sync	○	Cable	Fixed
[2]	Wired	Async	○	Cable	Fixed
[3]	Wireless	Sync	○	GPS	Fixed
[4]	Wireless	Async	×	WLAN	Fixed
[5]	Wireless	No info.	○	FM	Fixed
proposed	Wireless	Async	○	FM+ WLAN	Variable

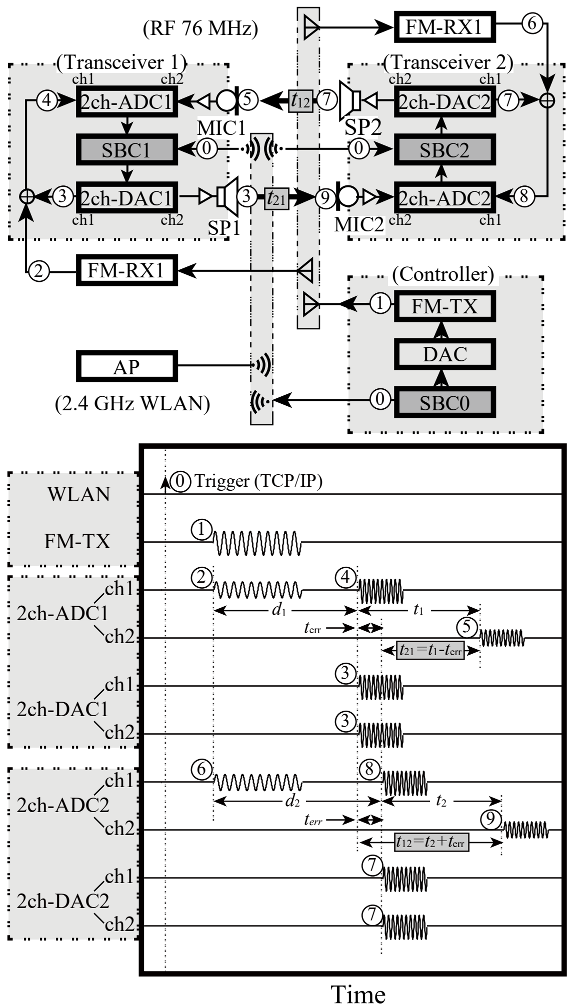

Fig. 1 Proposed acoustic probe.

0. The controller transmits a trigger message to transceivers via wireless local area network (WLAN). Two transceivers start sound transmitting and sound receiving as they receive the trigger message. The activation time of

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Transceiver #1 and #2 could be variable because the trigger message is exchanged at the application layer.

1. The controller transmits a burst signal from FM transmitter (FM-TX).
2. The FM receiver connected to the transceiver #1 (FM-RX1) outputs the received signal② to CH#1 of the stereo analog-to-digital converter (2ch-ADC1).
3. Stereo digital-to-analog converter (2ch-DAC1) transmits the burst signal③ to SP#1 and CH#1 of 2ch-ADC1, simultaneously.
4. CH#1 of 2ch-ADC1 receives the signal④ from signal③. Then the transceiver#1 calculates the d_1 , which represents the time difference between the arrival time of signal② and that of signal④.
5. The transceiver#1 receives the acoustic wave⑤ from the transceiver#2. Then the transceiver#1 calculates t_1 , which represents the time difference between the arrival time of signal② and that of signal⑤.
6. The transceiver#2 works as well as the transceiver1 and calculates d_2 and t_2, where ② and ⑥, ③ and ⑦, ④ and ⑧, ⑤ and ⑨ correspond.
7. Now the probe can calculate $t_{\mathrm{err}} = d_2 - d_1$, which represents the activation time difference between the transceivers #1 and #2

Finally, the probe calculates ToFs $t_{21} = t_1 - t_{\mathrm{err}}$ and $t_{12} = t_2 + t_{\mathrm{err}}$, where the effect of random latency at audio interface is cancelled.

3. Experiments and Results

The performance of the proposed system was evaluated in experiments. The proposed acoustic probe consists of SBC (Raspberrypi-4B, Raspberrypi), 2ch-DAC and ADC (DAC+ADC PRO, Hifiberry), SP (PT20K, Fostex), MIC (SPU0410LR5H-QB, Knowles), FM-TX (AE-STEREO-TX, Akizuki Denshi), FM-RX (RAD-P210S-H, Ohm Electric).

Figure 2 shows the layout of measuring experiment. The experiment was performed in a room of size 7.19 × 7.42 × 3.08 (m^3). As shown in the figure, the acoustic probe was set in the room. Five thermocouples are also set along the acoustic path as reference. In this experiment, the air temperature was changed from 27.39 to 24.12 (°C) by air conditioner, as shown in **Fig. 3** (red line). Note that the air conditioner was activated in Section III in the figure. Furthermore, two blowers (blower #1 and #2) are activated to in experiments. Specifically, the blower #1 was activated in Section I and the blower #2 was activated in Section II. The wind speed of the blower was set as 1.5 (m/s) at the center of the acoustic path.

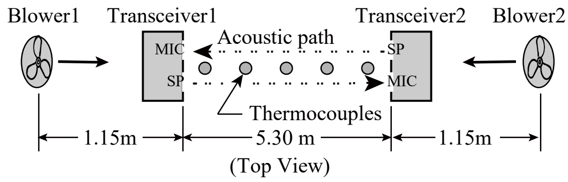

Fig. 2 Experimental layout

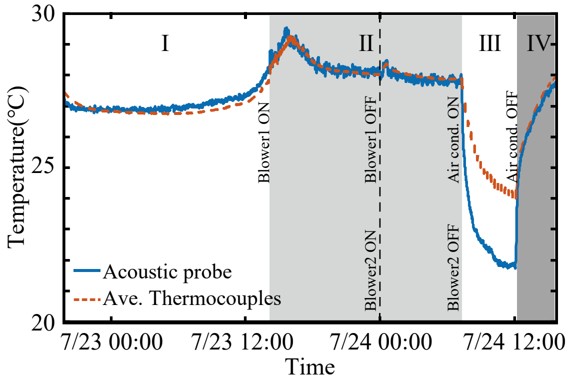

Fig. 3 Experimental results
(blue line: acoustic probe, red line: reference)

Figure 3 shows the experimental results. As shown in the figure, the proposed probe can precisely measure the air temperature in Sections I, II and IV (blue line). The mean-absolute-error between the acoustic probe and reference was 0.13, 0.01, and 0.29 (°C) in Sections I, II, and IV, respectively. It implies that the proposed method is able to measure air temperature within the error of 0.29 (°C) regardless of wind. However, it was also found that there is a difference between the acoustic probe and reference in Section III, where the mean-absolute error was 2.36 (°C). One of the reasons considered is that there exists the measurement latency at the thermocouples although the acoustic probe has no latency. Another reason can be the error of the acoustic probe caused by humidity. Sound velocity can also be varied with humidity, and it is possible that the air conditioner temporarily lowered the humidity in the acoustic path.

4. Conclusion

We proposed the asynchronous-type acoustic probe under fluctuation of audio latency, and we verified its accuracy of measurement under multiple environments. The result shows that the proposed method was found to be able to measure temperature with an accuracy of 0.29 (°C). This work was supported by JSPS KAKENHI Grant JP20H03103.

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