3P-22
Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 499-500
6-8 December, 2010

Sound Probe Network with ZigBee System
ZigBee システムを用いる音響波プローブ網の構成

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1. Introduction

Recently, it became possible to collect informations easily from sensors set up in a large-scale space via a wireless network with development of communication technologies. This sensing technique is expected as a temperature monitoring for air conditioning management in large facilities and so on[1)]. In our previous work, Data transmission and assembly technique for temperature measurement has been proposed which uses sound probes with wireless local area network (LAN)[1,2)]. However, the wireless LAN communication area has a certain limit based on the star topology that centers on access point, and the information transmission route is unique. Therefore, it is difficult to manage the wireless connection with single access point in a large-scale space. Then, we focus on the wireless network system that uses ZigBee / IEEE802.15.4 standard. The ZigBee system can support mesh networking, in which the nodes are interconnected with other nodes and there are multiple paths connecting each node. Connections between nodes are dynamically updated and optimized automatically depending on environment. Based on this mesh topology, the certainty of the communication can be improved because of preparing a lot of transmission routes, and the range of the network construction can be expanded freely. Therefore, this topology is suitable for the temperature monitoring technique with sound probe. In this paper, we compose equilateral triangular unit cell that consists of three sound sensing nodes equipped with the ZigBee nodes, and measures the air temperature distribution in the unit cell area as the practical verification.

2. Principle of Measurement System

We focus on unit cell components. The node that composes unit cell consists of a loudspeaker (SP) and a microphone (MIC). **Figure 1** shows the bi-directional sound probe formed with opposing these. The MIC receives the sound wave transmitted from the SP. A sound velocity, c, depends on the temperature and the wind velocity between the SP and MIC. A time of flight (TOF) is measured from transmitted and received waves by calculating cross-correlation. When the wind whose direction and velocity are defined as θ and v passes through the probe of length, L, the TOFs, t_{12} and t_{21}, can be measured as

$$t_{12} = L/(c - v\cos\theta), \quad t_{21} = L/(c + v\cos\theta). \quad (1)$$

The sound velocity, c, is given from eq. (1).

$$c = L(1/t_{12} + 1/t_{21})/2. \quad (2)$$

Relationship between the sound velocity, c, and the temperature, T, is defined as

$$T = -273.15 + \frac{273.15}{331.32^2}c^2. \quad (3)$$

Based on above, we composed an experiment system as shown in **Fig. 2(a)**. At each node, a signal generation and processing are carried out by A Slave PC. The SP and MIC are connected to the Slave PC via an A-D/D-A converter (USB-6212, National Instruments). The timing chart of the transmitting and receiving waves is shown in Fig. 2(b). Each probe is synchronized by the pulse signal from time base. Calculated TOFs are transmitted to ZigBee coordinator through the ZigBee system. The ZigBee coordinator controls all data reception and networks. The Master PC collects the measurement data and calculates the temperatures between each probe. Finally, the air temperature distribution in the unit cell area is calculated from these results.

3. Experimental Procedure and Results

We measured the air temperature distribution at 10 s intervals for 24 hours in a room whose volume is 7.3×7.4×3.1 (m^3) as shown in **Fig. 3**. Three nodes are located at apexes of an equilateral triangle whose edges are 3.7 m in length and on 1.8 m height from the floor. Here, the inside of unit cell is equally divided into three areas as indicated with short dashed lines in Fig. 3. The temperatures, T_1, T_2, and T_3, in the areas are calculated by eq. (4) so that the temperatures, T_{12}, T_{23}, and T_{31}, on the edges on the boundaries of unit cell are equally reflected

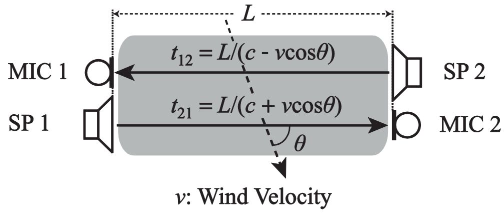

Fig. 1 Composition of bi-directional sound probe.

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to the temperatures in the areas.

$$
\begin{aligned}
T_1 &= (T_{12} + T_{31})/2, \\
T_2 &= (T_{12} + T_{23})/2, \qquad (4) \\
T_3 &= (T_{23} + T_{31})/2.
\end{aligned}
$$

Three thermocouple thermometers were set up in similar height as a reference of each area. To exclude the influence of the radiation heat, the thermocouples are covered with aluminum sheets. Moreover, to simplify the experiment system, the Slave PC1 in Fig. 2(a) shared the same PC with the Master PC and connected to the ZigBee coordinator. As measurement signal, we used an up-chirp signal from 7.5 to 12.5 kHz of 10 waves. The sampling frequency was 200 kHz. To change the temperature, we used an air-conditioner from 9:00 to 12:00 and from 16:00 to 18:00. To confirm the effect of the wind, we used fans which generate wind of 2 m/s at unit cell center. The fan1 was used from 13:00 to 14:00, and the fan2 was used from 15:00 to 16:00. The measurement results of the temperature in each area are shown in **Fig. 4**. The measured data are averaged in 5 min and plotted at 5 min intervals. As for the air temperature distribution measurement, the results by the probes almost agrees with reference in each area with the accuracy within 0.3 °C when there was no wind. Even when the wind was generated, the error was suppressed about 0.3 °C because the wind effect had been compensated by the bi-directional sound probe.

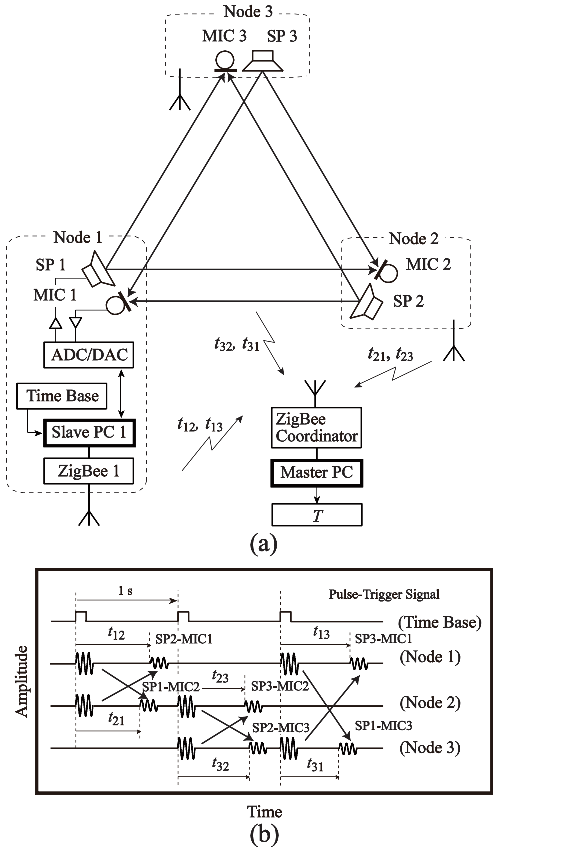

Fig. 2 Block diagram of experiment system: (a) Sound probe network with ZigBee system and (b) Timing chart.

4. Conclusion

We composed the sound probe network with ZigBee system for air temperature distribution measurement. Through the measurement, the operation of this system was confirmed. The air temperature distribution in the unit cell area could be measured with the accuracy of 0.3 °C, and the measured data was managed successfully through the ZigBee system. Thus, a variety of applied possibilities of the ZigBee system in the sound measurement field was suggested.

References

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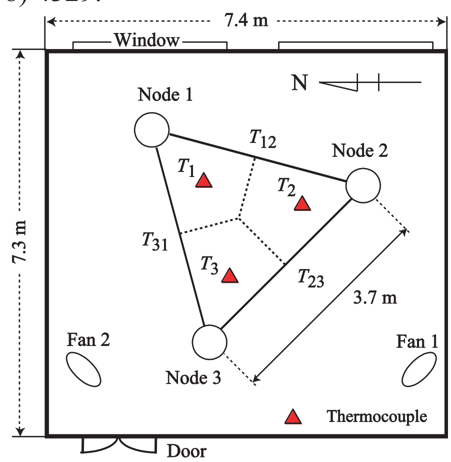

Fig. 3 Experiment setup.

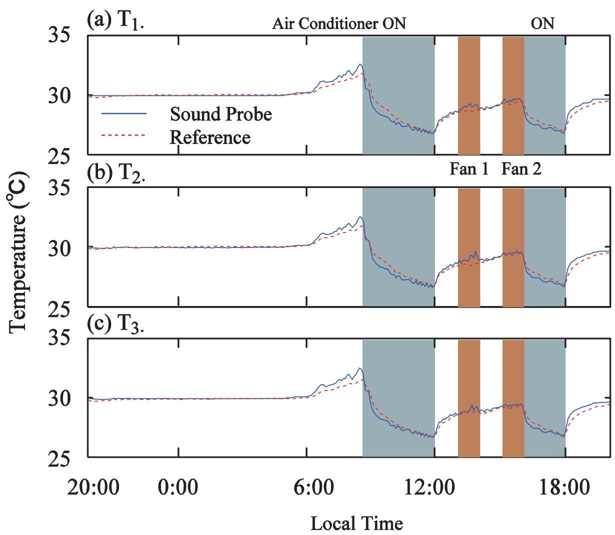

Fig. 4 Experimental results.