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Acoustical Positioning Method Using Transponders Without Clock Synchronization
時刻同期不要のトランスポンダを用いる音響測位

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1. Introduction

Indoor positioning is one of the important techniques that supports contextual awareness and ubiquitous computing. Recently, there are many indoor positioning techniques using ultrasound, as shown in **Figure 1** and **Table 1**. In such techniques, positioning is achieved by measuring multiple distances among anchors of known positions and terminal. However, existing techniques require accurate clock synchronization among anchors and terminals to obtain time-of-flight (TOF) of ultrasonic propagation between each anchor and the terminal. Moreover, to cover a wide range of area, numerous anchors are required because the attenuation rate of ultrasound wave increases as the frequency increase.

In this study, we developed a transponder-based indoor positioning method using audible sound. Proposed method has two advantages against conventional methods. First, the proposed method achieves positioning with simple devices since it does not require clock synchronization among anchors and terminals. Second, the proposed method is suitable for large-scale indoor positioning, because the attenuation rate of audible sound is smaller than that of ultrasound, and number of anchors can be reduced to cover a wide area. In this paper, we designed a transponder-based indoor positioning system using audible sound and evaluated its performance in experiments.

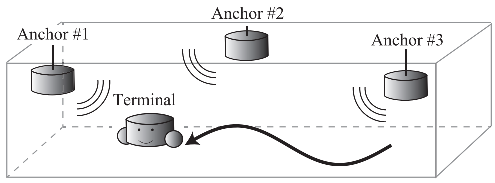

Fig. 1 Overview of indoor positioning.

Table 1 List of indoor positioning techniques[1-4].

Name	Synchronization	Number of anchors	Positioning Area	Frequency (kHz)	Positioning Accuracy
Active bat[1)]	Necessary	16	18 m^2	40	~0.1 m
Cricket compass[2)]		4	1 m^2		
Dolphin[3)]		7	2 m^2		
Phase accordance[4)]		2	4 m^2		~1 mm
Proposed method	**Unecessary**	**3**	**10 m^2**	**15**	**~0.1 m**

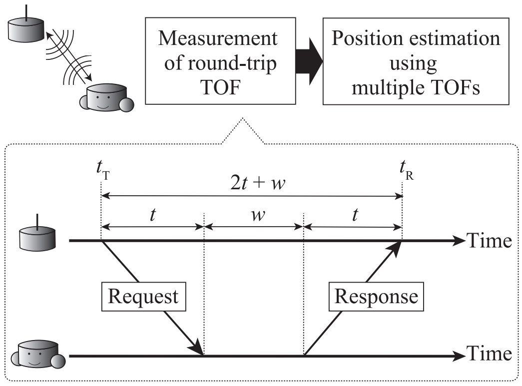

Fig. 2 Schematic view of proposed method.

2. Principles of Acoustical Positioning Using Transponders without Clock Synchronization

2.1 System Overview

Figure 2 shows a schematic view of our proposed method. We use multiple transponders, that produce response signals when they receive request signals, are installed on a ceiling or walls in an indoor room. To perform positioning, the terminal firstly measures round-trip TOF among the terminal and transponders using acoustical signal. The terminal then estimates its position by using multiple TOFs and position of anchors. In following subsections, we describe detailed signal processing of measurement of TOF and position estimation.

2.2 Measurement of Round-trip TOF

As shown in Fig. 2, the terminal firstly transmits a request signal to each transponder at t_T. The request signal propagates and reaches to the transponder with TOF of t. After waiting time w, each transponder transmits response signal to the terminal. The response signal propagates and reaches the terminal with TOF of t. If the terminal received the response signal at t_R, the relationship among t_T, t_R, and w becomes,

$$t = \frac{t_R - t_T - w}{2}, \qquad (1)$$

and we can measure TOF between the terminal and each transponder without clock synchronization.

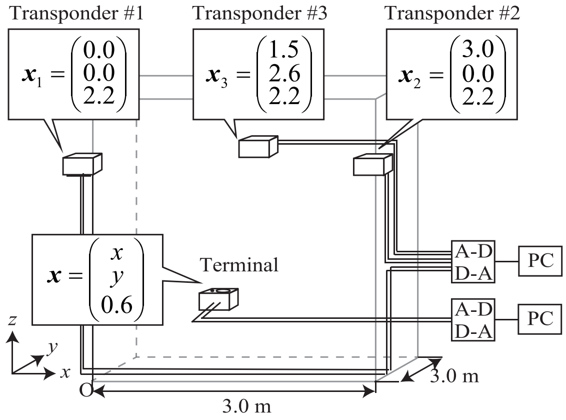

Fig. 3 Overview of experimental environment.

2.3 Position Estimation Using Multiple TOFs

After measurement of multiple TOFs, position estimation is performed by using TOFs and position of anchors. In following, we consider the case we have three anchors that exist at $\boldsymbol{x}_i = (x_i, y_i, z_i)^{\mathrm{T}}$ (i = 1, 2, 3). At first, the terminal calculates a distance between the terminal and anchor #i, ρ_i ,using TOF. If the true position of the terminal is $\boldsymbol{x} = (x, y, z)^{\mathrm{T}}$, the relationship among $\boldsymbol{x}$, ρ_i, and $\boldsymbol{x}_i$ becomes,

$$\rho_i^{\,2} = (x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2, i = 1, 2, 3. \quad (2)$$

Because Eq. (2) is a non-linear equation, the receiver solves Eq. (2) using iterative methods like Newton-Raphson method and obtains $\boldsymbol{x}$, as well as existing positioning schemes.

3. Experiment

Figure 3 shows the experimental environment. The experimental system was set up in an anechoic chamber of 3 m (W) × 3 m (D) × 2.5m (H). A loudspeaker (SD-9D4B, Clarion), microphone (CMS-64, Bosung Electron), A-D/D-A converters (USB-6212 and 6221, National Instruments) and personal computer (PC) were used as terminal and transponder. Calculation of transmitting signal and processing of received signal were performed on a measurement software (LabVIEW, National Instruments). Acoustical parameters, such as TOF and terminal position were calculated by software (MATLAB) on PC. We used modulated M-sequence of 7th order (chip time of 0.5 ms) as the request and response signals. The carrier frequency of the request and response signal was 15 kHz. The sampling frequency of A-D/D-A converter was 50 kHz. By using above parameters, the positioning was performed by changing the position of the terminal for 49 patterns. In each position, the positioning was performed for 10 times.

Figures 4 and 5 show experimental results. We firstly evaluate the performance of measurement of TOF using transponder. Figure 4 shows a histogram of the error of measurement distance obtained

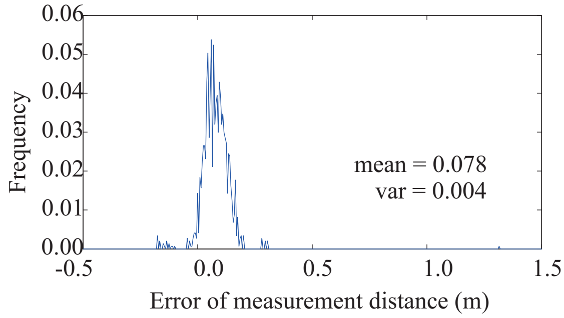

Fig. 4 Histogram of the error of measurement distance obtained in experiment.

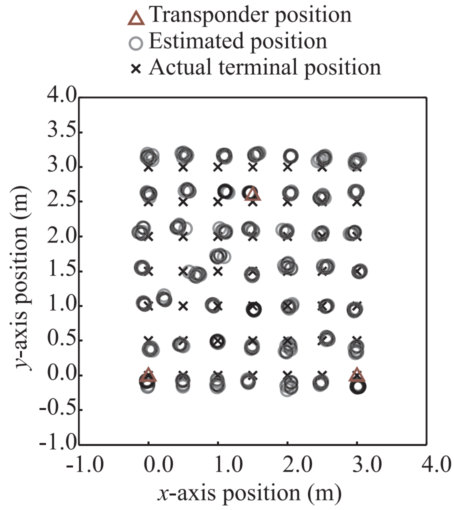

Fig. 5 Experimental result of positioning obtained in experiment.

from TOF measurement. As shown in this figure, the proposed method measures the distance between the terminal and the anchor with small error. Figure 5 shows an experimental result that shows a relationship between actual and estimated terminal position. We found that the proposed method achieved precise positioning – the minimum value, the maximum value, and the mean value of the positioning error was 0.03, 0.31, and 0.14 m, respectively. The obtained results suggest that the proposed system can achieve precise positioning without clock synchronization.

4. Conclusion

We proposed transponder-based indoor positioning method using audible sound and evaluated its performance. We found that our proposed method can achieve precise positioning without clock synchronization. Implementation of real indoor environment is our future work.

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