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Indoor Experiment of Acoustical Positioning Method Using Transponders

屋内におけるトランスポンダを用いた音響測位

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1. Introduction

Indoor positioning is one of the essential techniques for new location service such as indoor navigation and evacuation guide system. Existing methods such as ultrasound methods are suitable for small-scale area localization [1-5]. However, the methods have several problems. The one is that clock synchronization becomes complicated between transmitter and receiver. Another one is that ultrasound attenuates rapidly in the air as frequency increases. Hence, the number of ultrasound sensors increases as positioning area increases. Therefore, it is difficult to use existing methods directly for large-scale area localization.

On the other hand, the authors have proposed an acoustical positioning using transponder-based method and audible sounds [6]. An overview of the proposed method is shown in **Fig. 1**. The method requires no clock synchronization between the terminal and each transponder. In addition, audible sound can cover wide area compared with ultrasound. However, in reflection environments, such as actual indoor environment, the positioning accuracy may be deteriorated due to interference among direct and reflected signals. The purpose of this study is to perform large-scale area positioning by investigating the effect of reflection environment on positioning accuracy.

2. Principles of Acoustical Positioning Using Transponders Without Clock Synchronization

2.1 System Overview

The overview of proposed method is shown in **Fig. 1** [6]. Multiple transponders are set on a ceiling or walls. A terminal is located at arbitrary position. The proposed method measures each round trip time of flight (TOF) between the terminal and each transponder. An example of processing chart is shown in **Fig. 2**. First, the terminal transmits a request signal modulated by maximum length sequence (M-sequence #0) at t_{Ti} (i = 1, 2, 3). Second, multiple transponders record the request signal and detect the request signal by using cross-correlation function between the request signal and received one. After

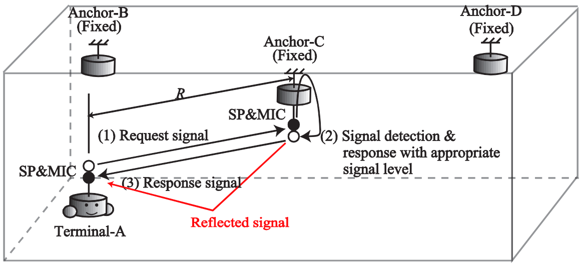


Fig. 1 Overview of indoor positioning.

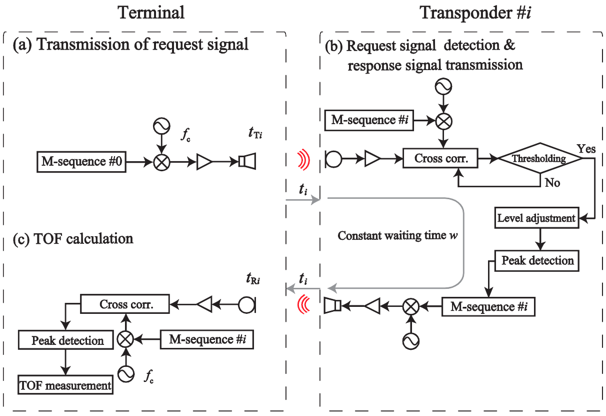
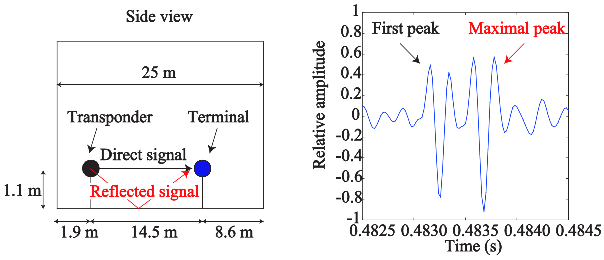
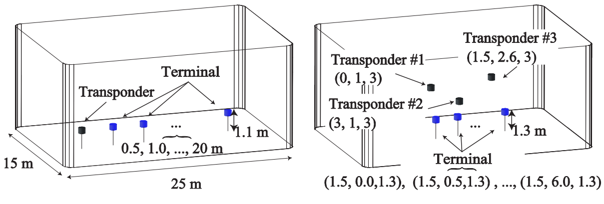


Fig. 2 An example of processing chart.



(a) (b)

Fig. 3 An example of cross-correlation function,
(a): example of location and
(b): cross-correlation function.



(a) (b)

Fig. 4 Overview of experiment environment,
(a): Ranging experiment and
(b): Positioning experiment.

constant waiting time *w*, each transponder transmits a response signal modulated by M-sequence #*i*. Finally, the terminal receives the response signal at t_{Ri}. By calculating the cross-correlation function between the received response signal and transmitted one, the terminal yields round-trip time of TOF of t_i.

$$t_i = \frac{t_{R_i} - t_{T_i} - w}{2}. \qquad (1)$$

Distances between the terminal and each transponder r_i are expressed as follows,

$$r_i = ct_i. \qquad (2)$$

The value of *c* is speed of sound. The terminal calculates its own position by using trilateration method such as Newton-Raphson method.

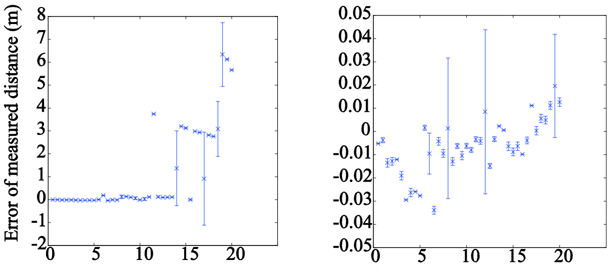
2.2 Effect of reflection environment

In actual indoor environment, positioning accuracy may be deteriorated due to interference among direct and reflected signals [**Fig. 3(a)**]. **Figure 3(b)** shows an example of cross-correlation function between the request signal and received one obtained in a gymnasium. As shown in this figure, there are multiple peaks, however the first peak (corresponds to direct TOF) is smaller than other peaks. Hence, the proposed method should not measure the maximal peak, but the first peak in reflection environment. In following experiments, we implemented above peak detection technique.

3. Experiment

Ranging and positioning experiments were carried out in a gymnasium of 25 m (W) × 15 m (D) × 10 m (H) shown in **Fig. 4**. Ranging and positioning experiment set up are shown in **Figs. 4(a)** and **4(b)**. Loud-speakers (P650-K, Foster), omni-directional microphones (c6797, DB Products), A-D/D-A converters (USB-6221, USB-6259, National Instruments) and personal computers were used as terminal and each transponder. Calculating transmitted signal and processing of received signal were performed on a measurement software (LabVIEW, National Instruments). The carrier frequency of the request and response signal was 5 kHz (bandwidth ±5 kHz). The sampling frequency of A-D/D-A converters were 50 kHz. By using above parameters, ranging and positioning were performed by changing the position of the terminal. In each position, the positioning was performed for 10 times.

Figures 5(a) and **5(b)** show the error of measurement distance obtained from TOF measurement by max and first peak detection. As shown in these figures, mean error and standard deviation of measured distance calculated using first peak detection. First peak detection method achieved acoustical ranging with average measurement error of 0.011 ±0.004 m when the terminal is within 20 m from the transponder. These results suggest acoustical positioning validity in large-scale area.



(a) (b)

Fig. 5 Ranging result,
(a): maximal peak detection and
(b): first peak detection.

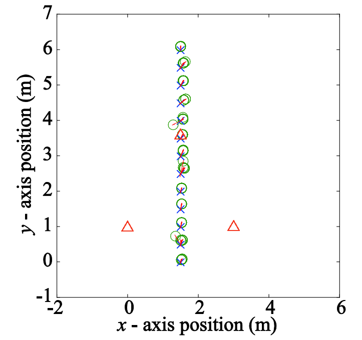


Fig. 6 Positioning result by using first peak detection

Figure 6 shows an experiment result of positioning that indicates a relationship between actual and estimated terminal position. That result shows parts of positioning accuracies are insufficient. However, most cases achieve within 0.15 m positioning. Hence, the proposed acoustical positioning method can achieve large-scale area positioning with enough accuracy, if the devices can measure direct TOF correctly. It is considered that positioning errors caused by effects of reflection. In the actual indoor positioning, positioning accuracy depends on terminal position.

4. Conclusion

In this paper, actual indoor environment positioning were performed. It was found that first peak detection is more effective than max peak detection of TOF in the reflection environment. First peak detection method achieved 0.011 ±0.004 m when the terminal is within 20 m from the transponder. The positioning results suggested validity of acoustical positioning.

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