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Ranging Experiment of Moving Object Using Acoustical Transponder and Doppler Shifted Reference Signal

音響トランスポンダ及びドップラシフト参照信号を用いる移動体測距実験

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1. Introduction

Recently, various location information services such as navigation, automation, and emergency managements have been realized with the spread of global positioning system (GPS) in outdoor environments. On the other hand, in indoor environments, it is difficult to utilize GPS directly because the signal reception level is attenuated. Therefore, an alternative is required for indoor positioning. To achieve low cost and accurate positioning, the use of acoustics is one of the technologies of choice today [1-4]. The authors have proposed acoustical transponder-based positioning method using measurements of round-trip time-of-flight (TOF) between a terminal and multiple transponders [5-6]. Different from existing techniques, the proposed method does not require clock synchronization among devices.

However, positioning of moving terminal is still challenging since there exists Doppler shift that affects the measurement of TOF seriously [7]. To cope with this problem, in this paper, we update our transponder-based TOF measurement scheme by introducing multichannel resampling technique [8].

2. Acoustical Positioning Using Transponder

2.1 System Overview

An overview of the transponder-based TOF measurement is shown in **Fig. 1**. The terminal and transponder have a pair of loudspeaker (SP) and microphone (MIC) for acoustical measurements each other.

Figure 2 shows the measurement procedure of TOF using audible sound and transponder [5-6]. The proposed method measures round-trip TOF between the terminal and transponder using following steps. (i) The terminal transmits a request signal to the transponder at time $t_{\mathrm{T}i}$. (ii) The transponder detects the signal and transmits response signal to the terminal after constant delay time d. (iii) The terminal receives the response signal at $t_{\mathrm{R}i}$. The round-trip TOF of t_i is calculated as

$$t_i = \frac{t_{\mathrm{R}i} - t_{\mathrm{T}i} - d}{2} . \qquad (1)$$

Then, the distance is calculated by multiplying t_i and speed of sound. Finally, the terminal estimates its position using multilateration method using distances between the terminal and multiple transponders.

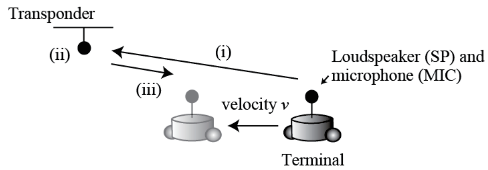

Fig. 1 Overview of moving object ranging using transponder-based method.

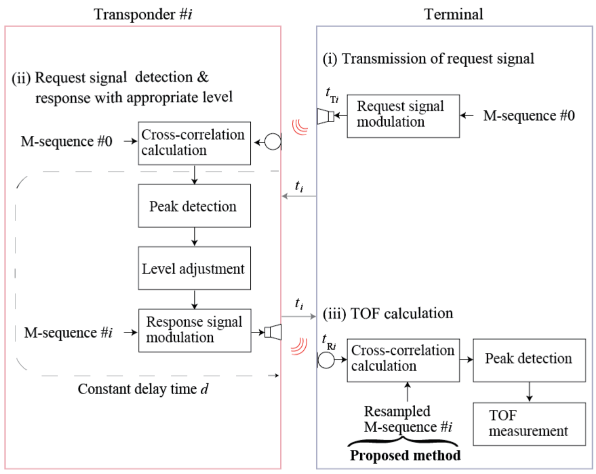

Fig. 2 Measurement procedure of TOF using transponder and Doppler shifted reference signal.

2.2 Problems and Solutions in the moving terminal positioning

In the case of positioning of moving terminal, there exists two problems; Doppler and TOF offset. When there exists relative velocity between the terminal and the transponder, the received signal has a frequency shift that affects the measurement of TOF. This is because our system utilizes the cross-correlation function between the received signal and reference signal to measure round-trip TOF. When the terminal received the response signal with movement, the peak value of the cross-correlation function becomes small while sidelobe level increases. Such decrease of peak-to-average-power-ratio (PAPR) of the

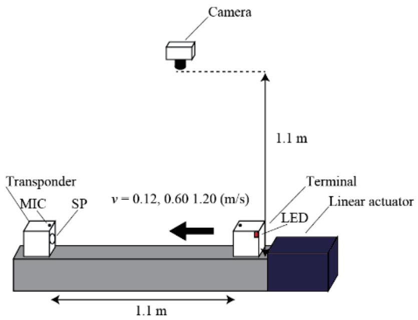

Fig. 3 Experimental setup.

Table 1 Parameters in experiment.

Modulation	BPSK
Other of M-seq	7th
M-seq feedback taps	7, 5, 4, 3, 2, 1, 0
Carrier frequency	5 kHz
Bandwidth	±5 kHz
Signal length	25.4 ms
Velocity	0.12, 0.60, 1.20 (m/s)

cross-correlation function increases difficulty of accurate TOF measurement. Furthermore, there exists TOF offset because the position of the terminal changes during steps (i)- (iii).

To cope with these problems, we utilize Doppler shifted signal as the reference signal [8]. Doppler shift is well known as an effect of expansion or contraction of the signal length. If the terminal receives a Doppler shifted signal when the terminal approaches to the transponder, the received signal length T_{R} becomes

$$T_{\mathrm{R}} = \frac{c}{c + v_{\mathrm{o}}} T_{\mathrm{T}}\,, \tag{2}$$

where c is the speed of sound, v_{o} is the terminal velocity, and T_{T} is the transmitted signal length. We calculate multiple Doppler shifted signals as reference when the terminal calculates the cross-correlation function with the terminal movement.

3. Experiment

We carried out ranging experiment in an anechoic chamber. The experimental setup is shown in **Fig. 3**. A loudspeaker (P650K, Fostex), a microphone (c9767, DB Products Limited), an A-D/D-A converter (USB- 6221, National Instruments) were connected to a personal computer by wire as a terminal and transponder. The signal calculation and processing were controlled by software (MATLAB, MathWorks and LabVIEW, National Instruments) on the PC. The parameters of acoustical signal were shown in **Table 1**. We measured round-trip TOF 10 times by changing the terminal velocity 0.12, 0.60, 1.20 (m/s), respectively. The PAPR of the cross-correlation function is shown in **Figs. 4(a)** and **4(b)**. As shown in the figure, the PAPR of the cross-correlation function increased slightly at the moving velocity 0.60 and 1.20 (m/s). Hence, it was found that the

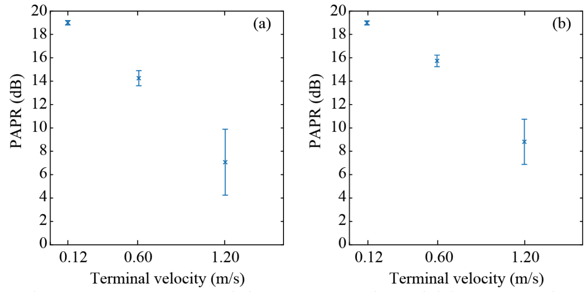

Fig. 4 PAPR (a) without Doppler shift correction and (b) with Doppler shift correction.

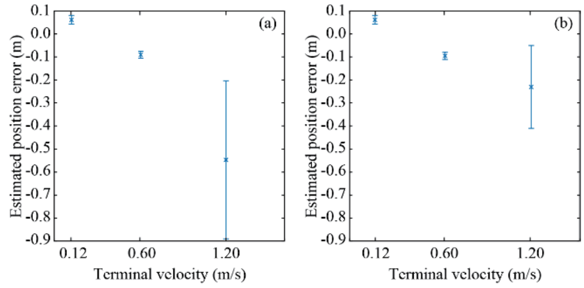

Fig. 5 Error of terminal position obtained from TOFs (a) without Doppler shift correction and (b) with Doppler shift correction.

Doppler correction would be effective when the velocity of the terminal increasing. The error of the ranging result is shown in **Figs. 5(a)** and **5(b)**. As shown in this figure, when the terminal velocity was 1.20 m/s, the error of the proposed method was much smaller than that of the conventional method. It was found that the error range was 0.05- 0.20 (m) at the terminal velocity 0.12- 1.20 (m/s).

4. Conclusion

In this paper, we confirmed the validity of the proposed method using the cross-correlation function with Doppler shifted reference signal in ranging experiment. The experiment result shows that when the terminal velocity was 1.20 m/s, PAPR and TOF accuracy was better than conventional method. Performance evaluation on positioning experiments with moving terminal is our future work.

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