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Mobile Evacuation Guidance System Using Digital Acoustic Communication
ディジタル音響通信を用いたモバイル避難誘導システム

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1. Introduction

In recent years, large facilities with complicated structure, such as stations, airports, and shopping malls are built. In case of an emergency such as fire, it is necessary to transmit information to visitors and to give appropriate evacuation guidance promptly. However, the appropriate evacuation route differs according to the location of visitors and the disaster occurrence. Therefore, "Evacuation guidance system" that gives appropriate evacuation guidance to each visitor is required.

This research aims to develop an effective evacuation guidance by utilizing the existing acoustic infrastructure deployed in large facilities, and widely spreading terminals such as smartphones. The usefulness of ultrasonic in indoor positioning has been clarified.[1, 2] In this paper, we designed the evacuation guidance system, and verified the basic performance of system through the experiment.

2. Proposed system

Figure 1 shows the outline of the proposed system. The system consists of a transmitter connected to a loudspeaker installed on a large facility and a receiver implemented as software in a terminal of the user. Since it is necessary to present optimum evacuation routes for visitors of different positions respectively, the waypoint method is used. Guidance using magnetism or inertial measurement unit (IMU) proposed as an example using waypoint method.[3)] In this research, from the viewpoint of using existing facilities and assuming evacuation with low visibility (e.g., fire smoke), we proposed a waypoint method using acoustic signals. By installing the loudspeaker on the branch point of the route as the waypoint and tracing the evacuation direction information (EDI) output as the acoustic signal from the loudspeaker, each visitor can obtain the suitable evacuation route respectively. In this research, the receiver is assumed to be a general smartphone which have microphones on the upper and lower part of the case body. Therefore, it is desirable to use transmission signal in the audible range. However, if adjacent signals interfere with each other, the receiver may not obtain correct EDI. To solve this problem, we use area-limited communication with audible sound. Specifically, the EDI on the terminal should be updated and presented only when the terminal passes just under the loudspeaker. To achieve this, digital acoustic communication and measurement of direction of arrival (DOA) are utilized. Then, by continuing to update the correct EDI just under the loudspeaker, the user can trace the safe evacuation route. To realize such a system, it is necessary to design a digital acoustic signal, the transmitter, and the receiver.

The transmitter modulates the EDI and outputs it as a digital acoustic signal from the loudspeaker. Specifically, we convert N-bit EDI $b_N = (b_0, b_1, \ldots, b_{N-1})$ into a frequency shift keying modulation signal. The transmission signal $s(t)$ is expressed by the following equation.

$$s(t) = \sum_{n=0}^{N-1} \tilde{b}_n(t), \tag{1}$$

$$\tilde{b}_n(t) = \begin{cases} \displaystyle\int_{F+\frac{B}{2N}}^{F+\frac{B}{N}} \sin\left(2\pi f t + \theta_f\right) df & (b_n = 0) \\ \displaystyle\int_{F}^{F+\frac{B}{2N}} \sin\left(2\pi f t + \theta_f\right) df & (b_n = 1) \end{cases} \tag{2}$$

$$\left(F = f_c - \frac{B}{2} + \frac{(n-1)B}{N}\right)$$

where f_c is the center frequency of the signal and B is the bandwidth of the signal. Also, θ_f is a random number uniformly distributed in the interval $[0, 2\pi)$. In this signal, the EDI b_N is expressed as the position of the pulse in the power spectrum of the signal regardless of b_N, and the frequency bandwidth is $B/2$. This makes it possible to reliably transmit EDI to the receiver. It is also suitable to measure DOA because the peak width of the cross-correlation function of the received signal is constant.

The received signal is processed in the receiver as follows. (i) The receiver measures DOA using two microphones mounted on the receiver. A relationship among θ, d (the distance between two microphones), and δt (time difference of arrival between two received signals) can be expressed as

$$c\delta t = d \cos\theta, \tag{3}$$

where c is the speed of sound. If c and d are known and the receiver can measure δt by calculating the cross-correlation function between the signals $y_0(t)$

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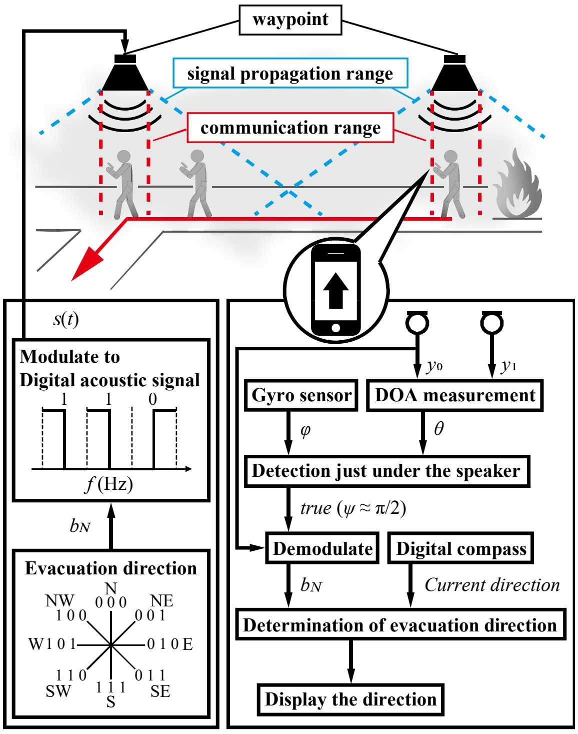

Fig.1 Outline of the proposed system

and $y_1(t)$ received by the two microphones, θ can be obtained.

(ii) The receiver calculates $\psi = \theta + \varphi$ where φ is an output of the gyro sensor inside the terminal. When the value of ψ is nearby $\pi/2$, it is judged that the terminal locates around loudspeaker. (iii) The receiver calculates Fourier transformations of $y_0(t)$ and $y_1(t)$. Then, EDI is obtained by demodulating the received signal. Based on the direction of the digital compass installed on the terminal, EDI is outputted on the screen. By repeatedly updating the EDI when the terminal locates around loudspeaker, the user can follow a safe evacuation route.

3. Experiment

We evaluated the basic performance of the proposed system, in experiments as shown in **Fig. 2**. Two loudspeakers (JBLPEBBLESBLKJN, JBL) were installed in an anechoic chamber. The distance between the loudspeaker and the center of the terminal model was 1.0 m. We also prepared the terminal model which consists of Raspberry Pi 3 Model B (122-5826, Raspberry Pi), Sense HAT (Sense HAT, RS Components), and ReSpeaker 4-Mic Array (B076SSR1W1, Seeed Studio). The distance between the two microphones on the terminal is 57.5 mm (**Fig. 2(a)**). The output signal has a center frequency $f_c = 5$ kHz, a bandwidth $B = 6$ kHz, and a sampling frequency of 16 kHz. First, different EDI is transmitted from each loudspeaker. Next, while the terminal model moves at a constant

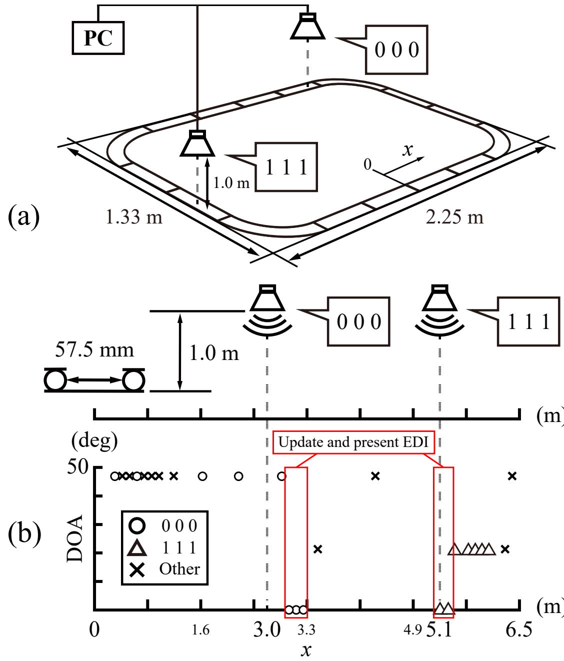

Fig.2 Experimental (a) environment and (b) result

speed (approximate 0.2 m/s), the receiver records the signal with the microphone mounted on the terminal model. The recorded signal was demodulated in the computer, and it was evaluated whether detection around the loudspeaker and the EDI were correctly transmitted.

The results are shown in **Fig. 2(b)**. We found that the receiver was able to update the correct EDI by combining information of transmitted EDI and digital compass output, only where the receiver locates around the loudspeaker.

4. Conclusion

We proposed the acoustic guidance system. In this system, an optimal EDI is transmitted from acoustic infrastructure by acoustic communication, and a received signal is analyzed by a terminal such as a smartphone to present an optimum evacuation route to the user. We made a prototype and evaluated its basic performance in experiments. As a result, it was found that the proposed method can update and present the correct EDI when the terminal reaches around the loudspeaker.

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