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Performance Evaluation of Acoustic Pedestrian-to-vehicle Communication System in Non-line-of-sight Environment
歩車間音響通信システムの見通し外環境における性能評価

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1. Introduction

Recently, there is a greater risk of car-pedestrian accidents when vehicles are traveling at low speeds [1]. To cope with this problem, advanced technologies are proposed to help prevent car-pedestrian accidents when vehicles are traveling at low speeds. For example, a vehicle detection scheme using a smartphone has been proposed by exploiting a high frequency switching noise generated by a motor unit in hybrid or electric vehicles (HVs and EVs) [2]. In addition, a pedestrian-to-vehicle communication scheme that exchanges informations of position and velocity of the vehicle using a high-frequency radio has been proposed [3]. Although these methods are effective, they are limited to HV and EV, or require dedicated hardware. Therefore, it is desirable if there are communication techniques that are easy to implement for both vehicle and pedestrian side.

As an alternative, we have proposed an acoustic pedestrian-to-vehicle communication system using orthogonal frequency division multiplexing (OFDM), which can achieve relative velocity measurement and communication simultaneously (**Fig. 1**) [4]. From experiments using vehicles, we found that the proposed system can measure vehicle velocity (measurement range: -10 to 10 km/h) within error of 1.3 km/h and communication without error at 4.5 to 40.5 meters, when the transmitter and the receiver are in the direct visual line of sight. However, experiments in other situations, such as an intersection with poor visibility has not been considered yet. In such environment, velocity measurement and communication performance may be affected by delay spreads and Doppler spreads. Hence, in this paper, we evaluate the performance of the proposed system in an outdoor environment with poor visibility.

This paper consists of four sections. Section 2 describes the outline of the proposed system. Section 3 evaluates the performance of the proposed system in an outdoor experiment in which a vehicle approaches a pedestrian in a non-line-of-sight environment. Section 4 concludes this work.

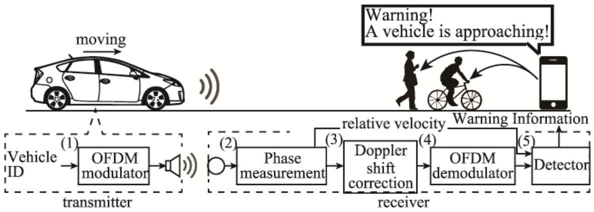


Fig. 1　Overview of proposed system.

2. Proposed System

Figure 1 shows a signal processing flow of the proposed system in the transmitter and the receiver. This system utilizes mobile information terminals such as smartphones that are widely used, and acoustic signal that is easy to implement for both vehicle and smartphone. In addition, acoustic communication is much sensitive to a large Doppler shift than other communication media in a dynamic environment. Hence, by utilizing this large Doppler shift, the relative velocity of the transmitter and the receiver can accurately be measured.

The transmitter is mounted on a vehicle, and it emits an acoustic signal from the loudspeaker. The acoustic signal was generated by (1) modulating the vehicle ID using OFDM. The receiver is mounted on a smartphone, and it alerts the user (pedestrian) when a vehicle is approaching by (2) measuring the relative velocity by detecting the Doppler shift of the received signal [5], (3) correcting the Doppler shift of the received signal, (4) obtaining the vehicle ID by demodulating the Doppler-corrected signal and (5) judging vehicle approaching.

In the phase measurement process, the receiver measures the Doppler shift as phase rotation of the received signal. The head and the end of the OFDM signal contain the same information so that the receiver can avoid intersymbol interference. The receiver calculates the inner-product of the head and the end of the OFDM received signal and measures the relative velocity V as the phase rotation of the inner-product value θ as follows:

$$V = \frac{c\theta}{2\pi f_c T}, \qquad (1)$$

where c is speed of sound, f_c is carrier frequency, and T is a signal bandwidth of the OFDM signal.

Table I Parameters used in experiment.

Parameters	Value
Number of subcarriers	64
Effective data rate (bps)	333
Cyclic prefix length (s)	0.004
Signal length (s)	0.012
Modulation	QPSK
Sampling frequency (kHz)	96
Carrier frequency (kHz)	6
Signal bandwidth (kHz)	2 - 10

3. Experiment

We tested the proposed system in a non-line-of-sight environment. **Figure 2** shows the experimental environment. The transmitter consists of a PC with a software modulator (LabVIEW, National Instruments), a digital-to-analog converter (USB-6212, National Instruments), an amplifier (PMA-390SE, DENON), and a loudspeaker (F77G98-6, TOPTONE). The receiver consists of an audio recorder (PCM-M10, Sony), and a PC with a software demodulator. We mounted the transmitter and the receiver on a vehicle (DBA-E11, Nissan) and a tripod, respectively. The vehicle with the transmitter approached the receiver at a speed of 5 and 10 (km/h). The transmitter calculated OFDM signal using parameters shown in **Table I**, and emitted it as sounds. The receiver recorded the sound and judged whether the vehicle is approaching or not.

Figure 3 shows the relationships between the distance *d* (in Fig. 2) and packet error rate (PER), true velocity, and measured velocity. We consider one OFDM signal as one packet. Since there is no receiver in the direction of travel of the transmitter, the true relative velocity between a vehicle and a pedestrian changes depending on the distance *d*, as shown in Fig. 3 (dashed line). Measured velocity is a value obtained by averaging velocities measured from the received signal every 5 m. The experimental results include 120 and 60 packets in Fig. 3(a) and (b), respectively. The error bar is the standard error of the measured velocity. When the distance *d* becomes longer, the proposed system failed communication and measurement. One of the reasons considered is the effects of delay spread. Due to the influence of delay spread, the position of the signal detection shifts, and measurement of velocity and communication are difficult. Since the cognitive distance for safety required for a vehicle at a speed of 10 km/h is 5 m [6], the proposed system achieves sufficient performance as an accident prevention measure.

4. Conclusion

We proposed the acoustic pedestrian-to-vehicle communication system, and performed the outdoor experiment in a non-line-of-sight environment.

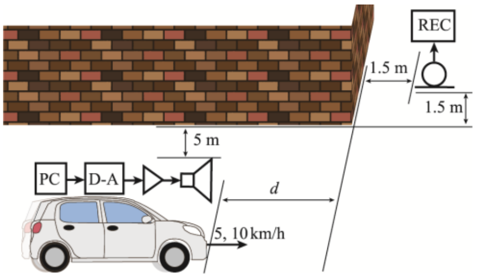
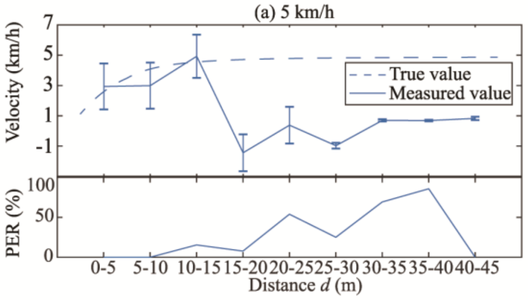


Fig. 2 Experimental environment.

(a) 5 km/h



(b) 10 km/h

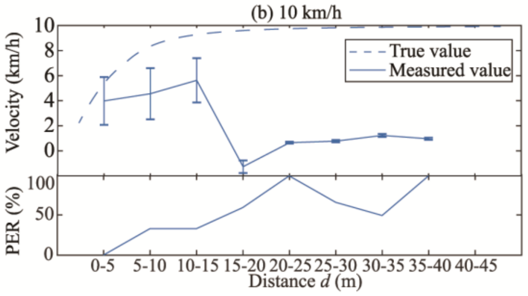


Fig. 3 Relationships between distance *d* and packet error rate, true velocity, and measured velocity; (a) 5 km/h, (b) 10 km/h.

When the transmitter and the receiver are in the direct visual line of sight, we achieved communication without error and measurement of vehicle velocity within error of 1.3 km/h. Even in a non-line-of-sight environment, we achieved communication without error and detection of vehicle approaching when *d* is 0-5 m. The proposed system achieves sufficient performance as an accident prevention measure. One of our future task includes improvement of the proposed system to cope with large delay spreads.

References

1. Institute for Traffic Accident Research and Data Analysis: ITARDA INFORMATION, **79**, (2009) [in Japanese].
2. M. Takagi, Y. Kawahara, and T. Asami: J. Info. Processing. **58** [10] (2017) 1617.
3. Y. Kaneko, and M. Hamaguchi: Jpn. OKI Technical Review, **78** [1], (2011) 72 [in Japanese].
4. Y. Umezawa, T. Ebihara, K. Mizutani, and N. Wakatsuki: Proc. 6th Global Conf. on Consumer Electronics, (2017), 311.
5. M. Sandell, J. V. D. Beek, and P. O. Borjesson: Proc. Int. Symp. Synchronization, (1995), 14.
6. National Highway Traffic Safety Administration: NHTSA-2011-0148, (2011).