Proposal of Ultrasonic Communication Method and Its Application to Position Estimation System

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Abstract

Recently, services using position information have been increasing. Radio waves and ultrasonic waves are used to acquire position information. Ultrasonic waves can be transmitted and received with existing speakers and popular smartphones. Therefore, there is no need for new devices for position estimation and their convenience is high. However, to the best of our knowledge, a modulation method and a symbol synchronization method for ultrasonic communication that are applicable to existing speakers and smartphones have not been proposed.

In this paper, we propose an ultrasonic communication method applicable to existing speakers and smartphones. Moreover, we propose a method of acquiring position information from the signal level of ultrasonic waves at a receiver based on the proposed ultrasonic communication method. Through an experimental evaluation, we confirmed the effectiveness of communications and position estimation.

1. Introduction

Recently, opportunities to use services based on position information have been increasing. For example, such services are utilized for marketing such as for coupon distribution and the analysis of behavior history based on position information. In order to provide these services, position information is acquired using radio waves, ultrasonic waves, and other waves. In particular, ultrasonic waves can be transmitted and received with existing speakers and smartphones. Therefore, there is no need for new devices for position estimation.

To the best of our knowledge, a specific communication method using ultrasonic waves has not been proposed. In this paper, we propose an ultrasonic communication method applicable to existing speakers and smartphones, and a position estimation method based on the proposed ultrasonic communication method.

This paper is organized as follows. Section 2 reviews related studies on communication and position estimation using ultrasonic waves. Sections 3 and 4 describe the proposed ultrasonic communication method and its evaluation. Section 5 proposes the position estimation method based on the proposed ultrasonic communication and evaluates it. Conclusions are presented in Sec. 6.

2. Related Studies

Here we introduce studies on communication protocol and position estimation using ultrasonic wave. Several studies [1]-[3] have proposed a communication protocol. In [1], the dependence of bit error on the modulation method (OOK, BFSK, and BPSK) was evaluated experimentally. However, this reference used frequencies not supported by existing speakers and smartphones. In [2] and [3], a protocol was proposed for ultrasonic communication using a smartphone as a receiver. In [2], BFSK was proposed and evaluated, but the utilization efficiency of the frequency is poor. In [3], a combination of multicarrier transmission and amplitude shift keying (ASK) was proposed. However, the use of the guard interval (GI) to reduce the effect of reverberation sound was not considered. In this paper, we also propose a communication protocol combining multicarrier carrier transmission and ASK but also consider the GI and error correction code.

In [4], an ultrasonic beacon using FHSS modulation was used to estimate the position. However, it required the simultaneous use of multiple speakers for position estimation and a high frequency not supported by existing speakers, meaning that it cannot be directly applied to a real environment.

3. Proposed Method

3.1 Modulation and demodulation method

Our modulation method uses a combination of multicarrier transmission and ASK for ultrasonic communication. Each bit information of digitized data is superimposed on each subcarrier used in the multicarrier transmission. The bit information, 0 or 1, corresponds to the amplitude on the subcarrier. The demodulation procedure is as follows. First, the receiver digitizes the voltage from the microphone. Next, the receiver performs
a fast Fourier transform (FFT) on the measured data and obtains the signal level of each frequency band. Then, the receiver judges the bit information as 0 or 1 depending on whether the signal level exceeds the threshold in each subcarrier. However, the threshold cannot be fixed because it is affected by the distance between the transmitter and the receiver, the volume of the transmitter, and the microphone reception sensitivity. To decide the threshold, we add a pilot signal indicating a known bit of 1 and a reference signal indicating a known bit of 0 to the transmitted signal. Using the average signal level of the pilot and reference signals, the receiver dynamically changes the threshold. The receiver decides the threshold at every symbol.

3.2 Symbol synchronization method

The purpose of symbol synchronization is to detect the beginning of a transmission frame. Figure 1 shows the frame structure and an example of the proposed synchronization method. The transmission frame consists of preamble and data symbols. The receiver repeats the measurement and FFT processing of the voltage from the microphone. "FFT Period" indicates the range for calculating the signal level for each subcarrier. The FFT period is shorter than the symbol length. When the preamble signal successively received $N$ times, the receiver recognizes the beginning of the first FFT period that detected the preamble as the start of the transmission frame. The reason for successively receiving the preamble $N$ times is to increase the reliability. The data symbol includes the GI to mitigate the effect of delay waves. Therefore, the receiver samples the data symbols after the GI has elapsed.

However, if the FFT period includes something other than the preamble symbol, as shown Fig.1, the receiver cannot detect the preamble signal. If a preamble signal is detected at the next FFT period, the detection of the preamble signal is delayed. Considering this delay, the symbol length must be twice the length of the FFT period and the GI.

4. Implementation and Evaluation

4.1 Implementation

We develop the receiver using an Android smartphone (nexus 5), and the transmitter using Raspberry Pi 3 (model B) and a speaker. The transmitter generates ultrasonic waves by reproducing the WAV file in which the preamble and user data are recorded. The WAV file is created by generating a sine wave using MATLAB.

4.1.1 Frequency bands and channel configurations

In our ultrasonic communication method, the channel consists of two pilot channels, two reference channels, eight data channels, and six error correction code channels. Table 1 gives the frequency channels and channel allocation. The pilot and reference channels are used to dynamically change the threshold for the decision of the bit information, 0 or 1. Each data channel carries one bit of user data, i.e., the eight data channels carry 8 bits per symbol. The error correction code channels are used to correct errors for user data. The correct error code is the Hamming (7, 4) code. Error correction channels [1] - [3] are used for the error correction of data channels [1] - [4]. Similarly, error correction channels [4] - [6] are used for the error correction of the data channels [5] - [8].

4.2 Evaluation and results

We evaluate the effect of the symbol synchronization from the viewpoint of success probability versus distance. Furthermore, we evaluate with and without the use of error correction codes. In the evaluation environment, the microphone of the receiver and the speaker of the transmitter are installed facing each other. The installation points of the receiver are at 0.5 m intervals in the range of 0.5 to 4.0 m. Figure 2 shows the evaluation configuration. The transmitter transmits a transmission frame consisting of the preamble (8 bit) and data (160 bit). Table 2 gives the evaluation parameters. The GI was determined from...
the length of the reverberation sound measured in advance. The value of $N$ in the symbol synchronization is two. For practical convenience, the sampling is performed every 20 ms to detect the preamble. The definition of the success probability is the ratio of the number of frames successfully received to the number of transmission frames.

We evaluate the proposed method in three ways: 1) without symbol synchronization and error correction, 2) with symbol synchronization and without error correction and 3) with symbol synchronization and error correction. The success probability in the above three cases is shown in Fig. 4. We confirmed that the success probability is improved by 10$\sim$30% in the range of 0.5$\sim$3.5 m by the symbol synchronization. Also, we confirmed that the success probability is improved by 20% in the 3.5 m by the error correction code.

5. Application to Position Estimation

We consider the estimation of the current position using the proposed ultrasonic communication method in an environment in which multiple transmitters are installed. Each transmitter transmits an ID related to the position information. However, if the receiver receives two or more IDs from multiple transmitters, there is a problem that we cannot estimate the position of the receiver. To avoid this problem, we propose a position estimation method to estimate the correct ID from the signal level of the ultrasonic wave. If the ID of the transmitter closest to the receiver is the correct estimation result, the signal level of the ultrasonic wave of that ID is considered to be higher than those of the other IDs. The proposed method is as follows. Each transmitter randomly transmits a frame every predetermined slot. This is to avoid the collision of frames transmitted from each transmitter. The receiver records the ID transmitted from each transmitter with the signal level of the ultrasonic wave for a fixed period. The signal level is the average value of the pilot channels on the preamble signal of that frame. This recorded time is the period for estimation. After that, we set the ID of the maximum signal level as the position estimation result within the estimation period. The estimation period must be two or more slot times to prevent the non-reception of a frame.

We confirm the effectiveness of the proposed method by experiment. The experimental space is a corridor on the basement floor as shown in Fig. 4. We install three transmitters 5.0 m apart and the receiver estimates at each measurement point. Transmitters A, B and C each transmit frame including an 8-bit ID of the position information, ID-A, ID-B, and ID-C, respectively. The slot time is set to 5 s, and the estimation period is set to 10 s. We estimate the position of the receiver ten times at each measurement point using the proposed method.

Figure 5 shows the number of estimation periods receiving each ID. The number of estimation periods receiving each ID is the sum of the number of estimation periods that received ID-A, ID-B, and ID-C at least once even within the estimation period. Figure 6 shows the number of estimated IDs. "Other" indicates the estimation result of any ID except for our preset IDs, or the non-reception of frames. If the estimation result is ID-A at a point where the distance from transmitter A is 0.0$\sim$2.0 m,
this estimation result is correct. Similarly, if the estimation result is ID-B at a point where the distance from transmitter A is 3.0–7.0 m, this estimation result is correct. If the estimation result is ID-C at a point where the distance from transmitter A is 8.0–10.0 m, this estimation result is correct. Figure 7 shows the signal level of each ID, which is the average value of the signal levels when ID-A, ID-B, or ID-C is received.

We consider the effectiveness of the proposed method for position estimation. When the distances from transmitter A are 0.0 and 5.0 m, multiple different IDs are received within one estimation period, as shown in Fig.5, but the estimated ID of these measurement points give the correct result as shown in Fig.6. This is because the signal level difference between ID-A and ID-B is different from 20 dBFS as shown in Fig.7. When the distance from transmitter A is 2.0 m or 6.0–8.0 m, the largest number of estimated IDs is for “Other” as the estimated ID shown in Fig.6. However, this is not due to the signal level since the receiver cannot receive the ID transmitted by the closest transmitter due to deterioration during the ultrasonic communication. From these results, we confirmed the effectiveness of the proposed method.

6. Conclusions

In this paper, we have proposed an ultrasonic communication method including a modulation method and a symbol synchronization method. The modulation method is a combination of multicarrier transmission and ASK. The symbol synchronization method is used to detect the beginning of a transmission frame. We confirmed the effectiveness of the modulation method and the improved success probability in the case of applying the synchronization method by the experimental evaluation. In addition, the success probability is improved by the error correction code. Moreover, we proposed a position estimation method using the ultrasonic signal level in an environment where multiple transmitters are installed and confirmed its effectiveness in experiments.

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References

[1] C. Li, D. A. Hutchins and R. J. Green: Short-range ultrasonic digital communications in air, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 55, No. 4, pp.908-918, 2008.
[2] S. Lakhwani, N. Pardamwar, N. Khewalkar: High frequency sound based device communication, International Journal of Advanced Research in Computer and Communication Engineering, Vol. 4, No. 3, pp. 367-370, 2015.
[3] H. Qian, M. Morise, M. Nitsuma and Y. Yamashita: Development of a communication system using sound signals in inaudible frequency bands, Proc. Information Processing Society of Japan, Interaction 2015, C50, pp. 913-916, 2015 (in Japanese).
[4] M. M. Saad, Chris J. Bleakley, T. Ballal and S. Dobson: High-accuracy reference-free ultrasonic location estimation, IEEE Transactions on Instrumentation and Measurement, Vol. 61, No. 6, pp. 1561-1570, 2012.