New Controlling Technique between Smart Devices Using Inaudible Frequency in Noise Environment

Myoungbeom Chung
Division of Computer Engineering
Sungkyul University
Anyang City, South Korea
e-mail: nzin@sungkyul.ac.kr

***Abstract*— Recently, existing technologies such as Wi-Fi socket communication, Bluetooth communication, Wi-Fi direct, etc., are used to control smart devices which are in close vicinity. However, those technologies have some problems. One problem is that the Wi-Fi socket communication cannot work when the socket server is not working. Another problem is that Bluetooth or Wi-Fi direct cannot work, if the Operating System (OS) of each smart device is different. Therefore, to address these problems, we propose a new control method for smart devices in close vicinity using high frequencies. High frequencies are mixed control signals, which are using 18 kHz ~ 22 kHz frequencies of audible range; most people cannot hear these high frequencies. Indeed, because the proposed method only uses the microphone and the speaker of smart device, there is no need for extra communication modules or communication server. In addition, it can be applied to most smart devices without reference to any OS. To evaluate the efficacy of the proposed method, we developed a music control application and a music player, to which we applied the proposed method. Then, we experimented with the developed applications at various distances and the control success rate was 97%. Moreover, when we use the high frequencies proposed method, the signal recognition rates of people close by was 5%. Therefore, the proposed method could be a useful method for control between smart devices in near.**

Keywords-Wireless communication; Signal processing; inaudible frequency; Controlling technique.

I. Introduction

The recent addition of modules to smart device has improved their performance and allowed users to perform activities such as playing games, listening to music, and watching movies. Individuals have begun to use more than a single smart device and to share data among smart devices. For example, an iPhone 5s user might also buy an iPad Air for its wide screen and fast data processing. The iPad Air user might also use a Galaxy S4 based on the Android OS. At first, socket communication involving Wi-Fi and servers was used to share data among smart devices [1][2]. Near communication methods using the Bluetooth module and Wi-Fi direct function have also been developed [3][5]. In addition, various communication methods use control technology between smart devices [6][10]. However, Wi-Fi-based socket communication technology requires a socket server, and if the socket server does not work, smart devices cannot share data or be controlled. Although Bluetooth technology does not need a server, pairing is needed to share data. In addition, Bluetooth technology has another weakness: It can be used only with devices with the same OS. Wi-Fi direct and Airdrop technology also have this weakness. Therefore, we need a new near control communication technology which enables sharing data between or controlling smart devices without pairing and regardless of OS.

Therefore, we propose a near control technology using high frequencies and the internal microphones and speakers of smart devices. High frequencies are sound signals which most people cannot hear and are between 18 kHz and 22 kHz of the audible frequency range (20 Hz–22 kHz). We use these high frequencies as control signals. Earlier research using high frequencies applied ultrasonic waves used by bats for measuring the distance to objects or finding obstacles, and most researchers studied tracing the position of people in indoor environments using high frequencies [11][12]. Bihler named high frequencies ultrasound waves and used them to trigger signals for data transmission to smart devices [13]. In this paper, we seek to improve the high frequencies of Bihler and to apply them as control signals between smart devices at a near distance. The high frequencies used by Bihler could introduce errors from sounds in the environment, so we protected against error generation by using two high frequencies: the first to send and the second to end it control signal. The first uses frequencies in the 18–22 kHz range, while the second uses only a fixed frequency.

To evaluate the performance of the proposed method, we developed a music remote control (control sender) and music player (control reception) applications to which we applied the proposed high-frequency method. We conducted a control experiment of the proposed high-frequency method using the two developed applications at various distances. The results showed a control accuracy of 97% within 5 m. When using the proposed high-frequency method, we tested how many people recognized the signal, resulting a recognition rate of less than 5%. Therefore, the proposed high-frequency method is useful in near wireless control between smart devices.

This paper is organized as follows. Section 2 explains the high frequencies used in the proposed method and the algorithm for the processing of the high frequencies in the smart device. In Section 3, we describe the music remote control and player applications. Finally, in Section 4, we

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discuss the results of the control experiment regarding the performance of the proposed method, and we present the conclusions.

II. INAUDIBLE FREQUENCIES FOR CONTROL AND CONTROL METHOD BETWEEN SMART DEVICES

This section explains the high frequencies used in the proposed control method between smart devices. The proposed high frequencies are between 18 kHz and 22 kHz. Two high frequencies are used in the proposed method. The first high frequency carries control information, so it uses one changeable frequency from 18 kHz to 22 kHz. The second high frequency sends only control end information, so it uses one fixed frequency. Thus, the proposed high frequencies consist of, first, a changeable high frequency and, second, a fixed high frequency as a control signal. The generating time of the first high frequency is m seconds and of the second high frequency n seconds. The reason for using two high frequencies in order is to prevent errors caused by unexpected noises in the environment. Fig. 1 presents an example of the proposed high frequencies. In Fig.1, the first high frequency uses 19 kHz and 20 kHz for the control signal, and the second high frequency 18 kHz.

As shown in Fig. 1, when the control device sends 19 kHz for the first high frequency over 0.2 s and 18 kHz as the second high frequency over 0.2 s, the smart device which receives the control signals completes analysis of the high frequencies at 0.5 s and executes a specific operation using the control signal (①). When the control signal sends 20 kHz over 0.2 s and 18 kHz over 0.2 s in order, the smart device completes analysis of the high frequencies at 1 s and executes another specific operation (②). In the example presented in Fig. 1, m and n seconds are both 0.2 s. We can see that, although noise occurs from 0.4 s to 0.5 s of the ① control signal and another noise occurs from 0.8 s to 0.9 s of the ② control signal, the proposed high frequencies work well. Figure 2 shows the work flow of the control method between smart devices using the proposed high frequencies.

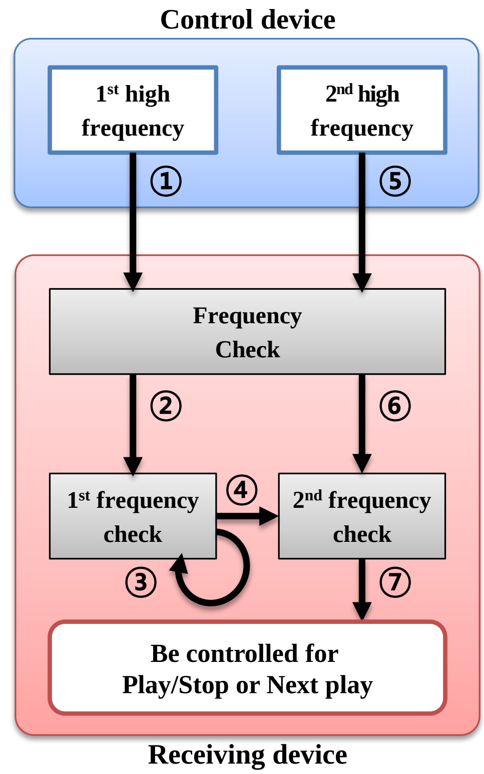


Figure 2. Work flow of proposed method using high frequencies

As shown in Fig. 2, when the control device sends the first high frequency (①), the receiving device uses a fast Fourier transform (FFT) algorithm to decide whether high frequencies are from the surrounding environment (②). If a high frequency is detected, the receiving device repeatedly checks if that same high frequency is sent consistently. If the high frequency continues for m seconds (③), the receiving device stops checking the first high frequency and waits for the second high frequency as the control end signal (④).

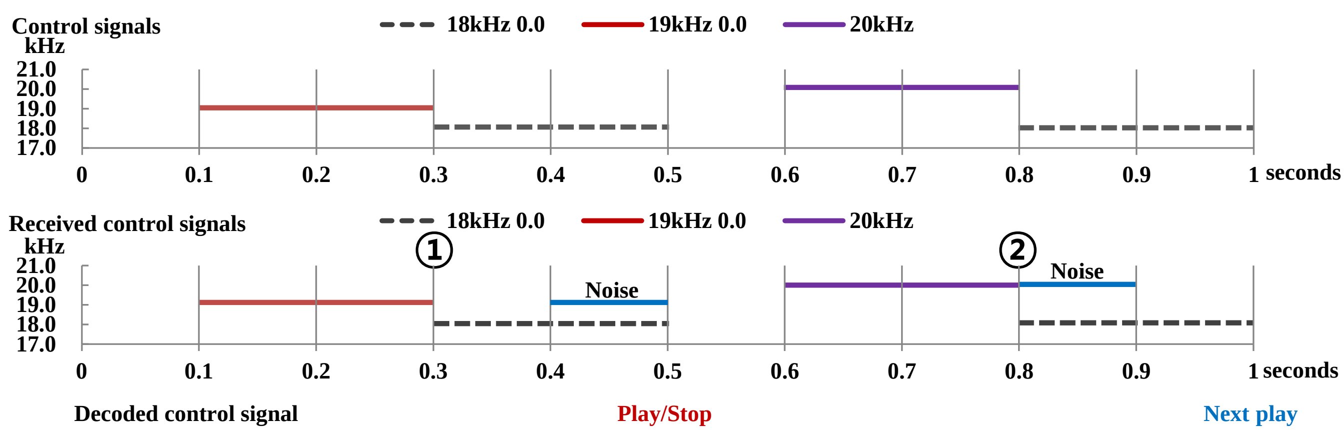


Figure 1. The example of proposed high frequencies for control between smart devices

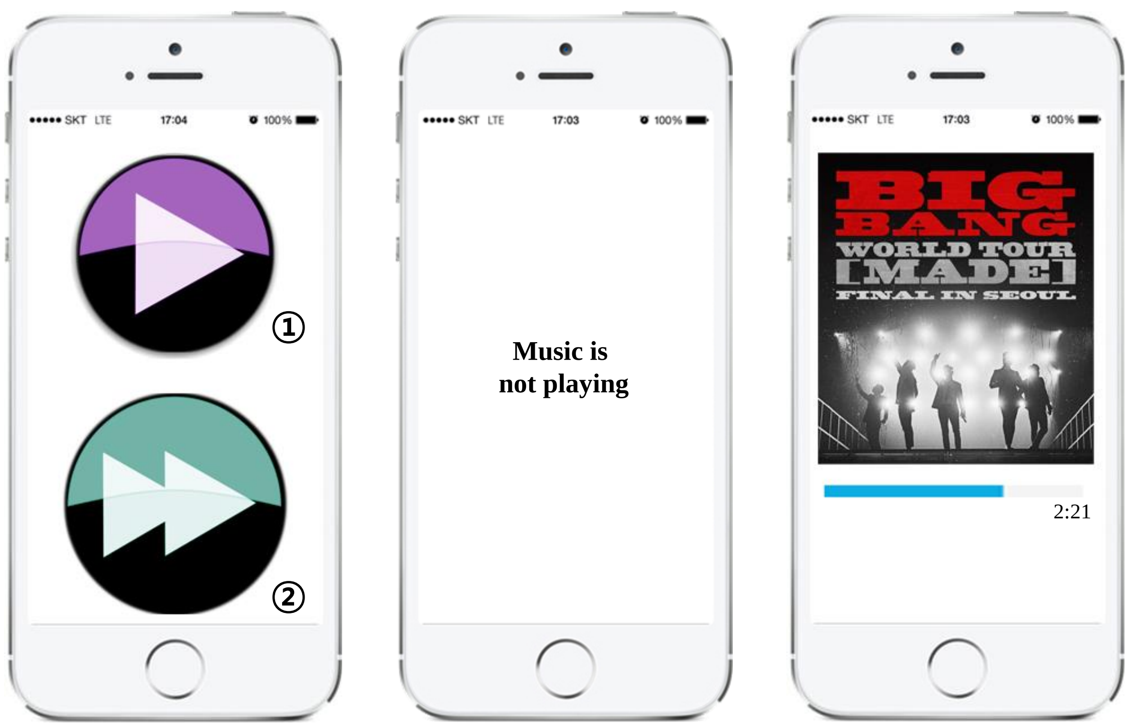
Then, if the control device sends the second high frequency (⑤), the receiving device recognizes the second high frequency over n seconds (⑥) and executes a specific operation (⑦).

III. EXPERIMENT WITH AND ANALYSIS OF THE PROPOSED CONTROL METHOD USING HIGH FREQUENCIES

This section describes the music remote control and player applications developed and the results for the performance of the proposed method's performance in the control experiment. The music remote control application sends the control signal from the control device, as described in Section 3, and has a toggle button, which can play and stop songs on the receiving device, and a next button, which enables moving to the next song (see Fig. 3(a)). The toggle button (①), which starts and stops songs (Fig. 3(a)), uses 19 kHz as the first high frequency and 18 kHz as the second high frequency. The next button (②) (Fig. 3(a)) uses 20 kHz as the first high frequency and 18 kHz as the second high frequency. We use 0.2 s as m seconds of the first high frequency and 0.2 s as n seconds of second high frequency. The music player application receives the proposed high frequencies and plays a song (Fig. 4(b) and (c)). The music player application starts with the "Music Stop" screen (Fig. 4(b)). When it receives the high frequencies for playing songs from the music remote control, the music player application displays song information and plays the song (Fig. 4(c)). The image (①) in Fig. 4(c) shows information about the song being played and a progress bar (②), indicating the duration of the song.

We tested the accuracy of the proposed high-frequency method when varying the distance between the music remote control and player applications. The tested distance between the smart devices was 1 m and 5 m, with 100 tests performed at each distance using the play, stop, and next buttons. The test environment was a laboratory with a quiet indoor environment with a noise level of approximately 40 dB, the average noise level in homes. Figure 5 shows the results for distance from the control experiment. The accuracy of all control operations within 3 m was more than 95% and within 5m, more than 95%. While the music player application was playing, the accuracy of the stop and next control operations was 96.8% within 5 m. Thus, the proposed high frequencies are robust amidst interference from other unexpected sound signals.

Next, we tested the recognition rates among surrounding people when using the proposed high frequencies. The experiment environment was the same as in the previous experiment, and the distance between smart devices was 3 m. Each control operation was performed 10 times, and the 10 participants were students in their 20s who were in the same place for each operation. The signal recognition experiment noted the number of count cognitions among participants when using high frequencies, Table 1 shows the results for signal recognition using the proposed high frequencies.



(a) (b) (c)

Figure 3. The music remote and music player applications applied the proposed method: (a) The main screen of the music control remote application, (b) The screen of music player application when song stops, (c) The screen of music player application when song is playing

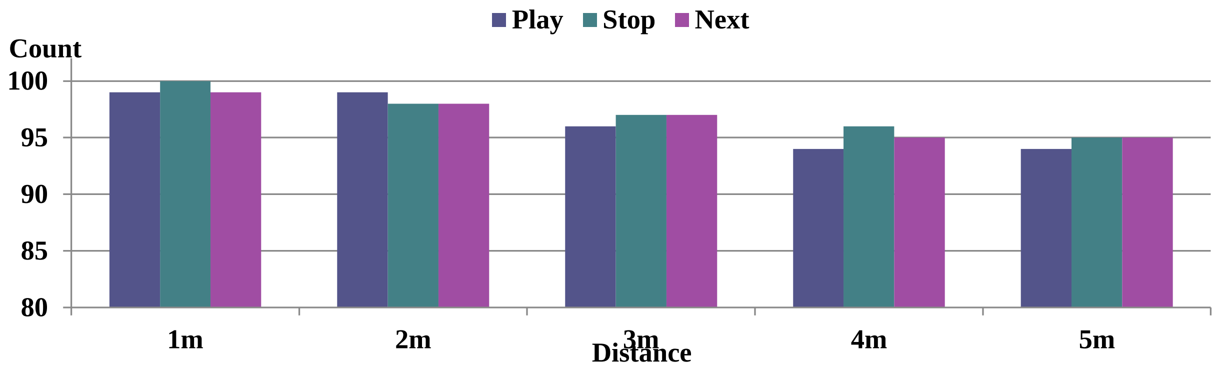


Figure 4. The result of control operation using high frequencies according to distance between smart devices

TABLE I. THE RECOGNITION RESULT OF PARTICIPANT ABOUT HIGH FREQUENCIES FOR CONTROL

Control	Play	Stop	Next
P1	0	0	0
P2	0	0	0
P3	0	0	0
P4	6	2	1
P5	0	0	0
P6	0	0	0
P7	0	0	0
P8	0	0	0
P9	2	1	2
P10	0	0	0

As shown in Table 1, participants' average recognition value was less than 5%. When it was silent, 1 of the 10 participants recognized the high frequencies 6 times, while another recognized the high frequencies twice. Eight participants did not recognize the proposed high frequencies. When a song was playing, 2 participants recognized the control signal. One participant recognized twice and another once. Participants recognized high frequencies in the stop operation less frequently than in the play operation, even though the 2 control signals used the same high frequency. This difference likely is explained by the playing music which covered the sound of the high frequencies. Two participants recognized the high frequencies for the next operation, which were different than the play and stop operation frequencies. The next high frequencies were generated while a song was playing; 1 participant recognized the signals once and 1 participant twice. After the experiment, we conducted a hearing test for the 2 participants who recognized the proposed high frequencies and found that they could hear the 18 kHz high frequency. However, the average recognition value of the 3 operations using proposed method was less than 5%, so we confirmed that the proposed high frequencies did not affect people in the area of the smart device.

IV. CONCLUSION AND FUTURE WORK

In this paper, we have shown that the proposed method using high frequencies can effectively control smart devices at a close range without a socket server or pairing. This method can easily use any OS on smart devices, even if the smart devices have different OS. Therefore, the proposed high-frequency method can be a useful technology in networking fields, such as near wireless communications and near control between smart devices.

In future research, we will study the effectiveness of advertisement technology in smart televisions using the proposed high frequencies with smart devices. Additionally, we will research new signal processing technology for data and information transmission using only high frequencies.

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