Detection of a Robust High-Frequency Range via Noise Analysis in a Real-World Environment

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Abstract. Recently, many studies have been conducted on using inaudible high frequencies for wireless communication based on smart devices and data transmission algorithms. However, many studies have identified a problem such that transmission accuracy is extremely low because of ambient noise in the real-life environment. To solve this problem, we proposed an application and server system. The proposed application can gather many sounds, including those with high frequencies; the gathered high frequencies are sent to a server system that can detect a robust high-frequency range via statistical processing. We tested the proposed application's ability to gather noise and high frequencies for a certain period of time to evaluate performance. According to the testing results, the proposed application and server system could detect a robust high-frequency range via noise analysis in real life. Therefore, the proposed application and server could be a useful technology for future research on inaudible high frequencies.

Keywords: Smart device · High-frequency communication · Robust high frequency · Wireless communication

1 Introduction

Recently, because of advancements in wireless communication technology and smart device hardware, many studies have been carried out on data-correcting technologies based on smart devices. Moreover, related research has evaluated the user work rate of these technologies using smart devices and smart bands [1, 2]. In addition, many studies on user movement and activity analysis related to technologies have used various built-in sensors for smart devices [3, 4]. Smart device usage analysis focusing on user behavior has been carried out as applications installed in smart devices [5]. Most of these studies have made use of server coupling technology for big data analysis [6]. For example, user movement and activity analysis technologies send correcting data about many people's movements and location to a server. And then, analysis of information on a server can be employed for various service models, such as hotspots,

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favorite routes, and so on [7]. In addition, smart device usage analysis has been carried out, such as when the user sends usage data about the smart devices to the server and the server makes a decision as to whether the user is a smartphone addict by analyzing the receiving data [8].

In another stream of research on smart devices, many new communication and transmission technologies have been proposed using the devices' built-in speakers and microphone. Kim proposed user certification technology between personal computers and smart devices using high frequencies in the audible frequency range of 18–22 kHz [9]. In addition, Bihler developed a smart museum guide application using piezo speaker and smart device [10]. Chung proposed not only smart advertising service technology at a short distance, but also multi–data sharing technology among several smart devices using high frequencies [11–13]. However, because these technologies only use high frequencies that are inaudible to people, these frequencies often receive interference from the ambient that is present real life. Thus, the data transmission accuracy of Bihler's application was only 50 % when used in a real-world setting; moreover, Chung's proposed method would not work well in an actual environment because the test environment only comprised fixed noise from a speaker.

In this paper, we propose an application and server system for the detection of a robust high-frequency range via noise analysis in the real-life environment. The application uses a built-in microphone to gather ambient noise and analyze high frequencies in it. To gather and analyze high frequencies using the built-in speakers of smart devices, we developed the application based on a fast Fourier transform (FFT) algorithm. When a user carries some day with a smart device, the application can gather all noise and analyze high frequencies around the user anywhere and at any time. The proposed server system receives the information on high frequencies gathered by smart device and detects a robust high-frequency range through statistical processing after saving the high frequencies to a database. To confirm performance of the proposed application and server system, we carried out an experiment over the course of seven days. According to the result of the experiment, we can state that the proposed application and server system was able to detect the robust high-frequency range without interference from ambient noise in the real-world environment. Thus, information on the robust high-frequency range from the proposed application and server system can be used to increase the data-transmission accuracy in many studies using high frequencies.

The present paper is organized as follows: In Sect. 2, we describe the scene organization and workflow of the proposed application and server system for the detection of the robust high-frequency range. In Sect. 3, we explain the experiment to confirm the performance of the proposed system; a conclusion and a discussion of future research are provided in Sect. 4.

2 An Application for the Analysis of Ambient Noise and a High-Frequency Range Detection System

In this section, we explain the proposed system, which analyzes high frequencies from ambient noise using a smart device and sends the high frequency to the server for detection of a robust high-frequency range. Figure 1 shows the workflow of the proposed application and server system.

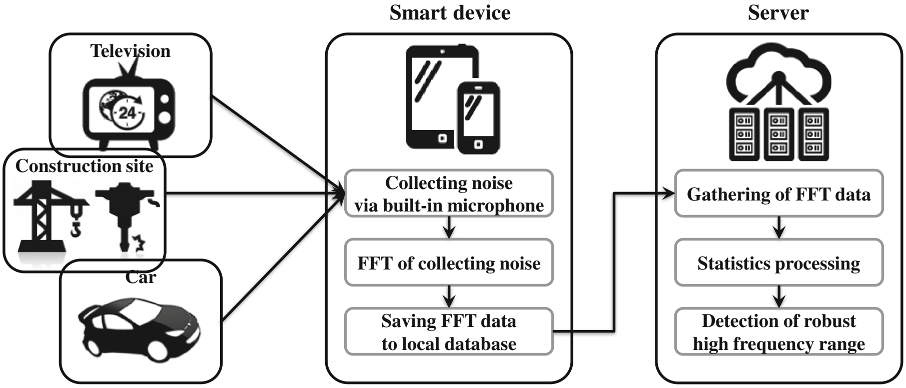

Fig. 1. The workflow of the proposed system

In Fig. 1, the application of the smart device collects various types of noise, such as television sounds, construction noise, vehicle sounds, and so on in a real-world environment via the smart device's built-in microphones. The application processes the gathered noise to generate FFT data in real time, and it selects high-frequency data from frequencies of 15–22 kHz, which are inaudible to people. Following this, the application saves the selected high-frequency data to the smart device's local database; the high-frequency data are saved up to a fixed quantity, at which point the application sends the data to the server system and deletes them. Next, the server system collects high-frequency data from smart devices and carried out basic statistical analysis. Thus, the proposed system detects a robust high-frequency range in real time through this process.

The proposed application gathers high-frequency data by 100 Hz; it saves high-frequency data to the database after confirming that high frequencies are present according to number of frequency bins. The reason for division by 100 Hz is that most of the existing research has used such division, and it can avoid interference from each high frequency. Thus, the application gathers high-frequency data from ambient noise and carries out FFT processes. Next, the server system saves received high-frequency data from the smart device to a data collection table with the collection time. Simultaneously, the server saves the result concerning whether high frequencies are present for each datum to the statistics table. When the server saves the high-frequency data to the data collection table, it does not process any data, and it saves the original number of high frequencies from 15–22 kHz from the smart device. The data collection table has

Table 1. Data collection table schema for saving FFT data received from the smart device.

Schema	Type	Description
no	int(10)	Number of counting of FFT data
time	int(13)	Time stamp when FFT data were saved on smart device
s150 … … s220	int(2) … … int(2)	Frequency bin value of FFT data at 15.0–22.0 kHz
reg_date	int(13)	Time stamp when FFT data from smart device was saved

the schema shown in Table 1. In Table 1, "no" counts the row number of FFT data, and "time" means the saving time of the FFT data on the smart device. Moreover, s150 is the number of high-frequency bins at 15.0 kHz, and s220 is the number of high-frequency bins at 22.0 kHz. Finally, reg_date refers to the time FFT data were saved in this server table. The statistics table for the detection of the robust high-frequency range has the same schema as in Table 1. However, this table does not have a time field, which means that the time stamp for the FFT data is saved on the smart device.

Because the statistics table only counts whether there is a high frequency, when the server saves high-frequency data to the data collection table, the statistics table is updated by counting the existing high-frequency data. Then, when we count the number related to each high frequency from the statistics, we were able to identify some high frequencies that often occur in the real-world environment; moreover, we could detect the robust high-frequency range from rare high frequencies in the statistics table.

3 Experiments and Evaluation Using the Proposed Application and Server System

This section introduces an application developed to gather ambient noise around smart devices; here, we analyze the experiments and evaluate the proposed application and server system. First, we developed the application based on iOS; Fig. 2 shows the main screen of the application. In Fig. 2, the graph located on the left is the bin number of each high frequency from the ambient noise gathered by the built-in microphone; we can confirm high frequencies at 16.7, 16.8, 18.1, 18.2, 18.9, 19.0, 19.1, 19.2, and 20.7 kHz. The application analyzes current ambient noise currently and shows the graph according to the FFT data when the user touches the "Frequency check" button located on the right. To analyze the FFT data, for this experiment, we used a 48,000 sampling rate and the FFT library provided by Baoshe Zhang [14]. When a user touches the "Start gathering noise" button, the application starts collecting and analyzing ambient noise at regular intervals, and the button is changed to "Stop gathering noise." The total duration of ambient noise collection is shown as the GTime, and the total duration of the main screen is 28 min and 21 s. When the user touches "Send gathering data" button, the application sends the total FFT data collected up to that time to the server system; it shows the final sending time at "Last send" located at the bottom right. Moreover, when the volume of collected data exceeds a specified amount,

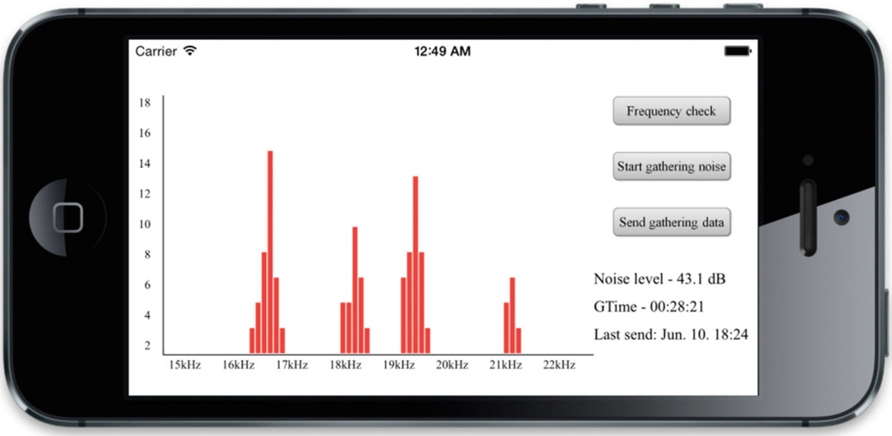

Fig. 2. Main screen of the proposed application for collecting of ambient noise

the application sends the FFT data to the server automatically even if the user has not touched the "Send gathering data" button.

We carried out an experiment on the detection of the robust high-frequency range using the proposed application and server system. A participant used a smart device running the proposed application in everyday life for 7 d. Running time of the application was from 9:00 to 10:00, 12:00 to 13:00, and 18:00 to 19:00; thus, the total running time over the 7 d was 21 h. The participant's working area varied during the experiment, including home, cafés, a laboratory, the subway, bus stop stations, crowded buses, and so on. The application collected and analyzed ambient noise at 2-min intervals and the participant touched "Send gathering data" button at each ending time to send the collected FFT data to the server. The server systems for the FFT data saving and statistics processing were Apache 2.2.14, PHP 5.2.12, and MySQL 5.1.39, and the server system comprised an Intel® Core™ i5 CPU 750 and 8G RAM. Through this experiment, the data collection table saved 630 records about high-frequency data from ambient noise in a real-world environment; Fig. 3 gives an example of some records in the data collection table. In Fig. 3, the "time" field is the saved time of high-frequency data of the row as a time stamp. For example, the time value of no 1 is 1463356872, referring to 09:01:12, May 16th, 2016.

A total of 71 fields were present in the data collection table from save frequency bins of s150 to s220 for each high frequency, and Fig. 3 shows a sample of these fields. In Fig. 3, the value of reg_date from no 1 to no 10 is the same; this is because reg_date is the time at which high-frequency data were saved from smart device to server, and rows 1–10 were saved at the same time. Below, Fig. 4 shows the processing result of statistics table, which determines whether each high frequency is present from the data collection table.

Figure 4 represents a statistical graph concerning high frequencies that the participant gathered over 21 h; we can see that some high frequencies were not evident, such as 15.0–15.3, 15.9–16.2, 16.4–16.6, 17.3–17.6, 18.4–18.6, 18.8, 19.0–19.2, 19.4,

no	time	s150	s155	s160	s165	s170	s175	s180	s185	s190	s195	s200	s205	s210	s215	s220	reg_date
1	1463356872	1	1	1	0	3	2	0	0	0	1	0	0	0	4	0	1463360475
2	1463356992	0	3	0	4	6	0	0	0	0	1	0	0	0	0	0	1463360475
3	1463357112	0	3	0	4	6	0	0	0	0	1	0	0	0	0	0	1463360475
4	1463357232	0	0	0	0	3	0	6	0	0	3	3	0	0	0	0	1463360475
5	1463357352	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1463360475
6	1463357472	0	0	0	0	0	0	0	0	0	0	11	0	0	4	0	1463360475
7	1463357592	0	11	0	4	0	0	0	0	0	0	0	0	0	0	0	1463360475
8	1463357712	0	0	0	2	0	0	2	0	4	0	0	0	0	0	0	1463360475
9	1463357832	0	3	0	4	6	0	0	0	0	1	0	0	0	0	0	1463360475
10	1463357952	0	0	0	0	0	0	12	0	0	1	0	0	2	1	0	1463360475

Fig. 3. Example of FFT data collection from a smart device

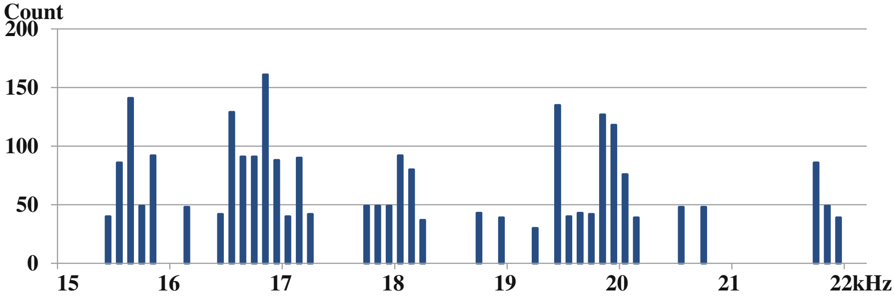

Fig. 4. The high frequency chart from the statistics table of the server

20.3–20.5, 20.7, and 20.9–21.6 kHz. Thus, we could detect robust high-frequency ranges that hardly ever occur from ambient noise when we use the proposed application and server system. Moreover, we consider that the detected robust high-frequency range could not receive interference from ambient noise, which would occur in real life when many researchers sought to use the range.

4 Conclusions and Future Work

In this paper, we proposed an application that can gather and analyze high frequencies from ambient noise using the built-in microphone of a smart device and a server system that can save high-frequency data to database and process statistics from the collected data for the detection of the robust high-frequency range. From the experiment, we confirmed that the proposed application could analyze high frequencies from ambient noise in real time and send the FFT data to the server. In addition, we showed that the server system can distinguish high frequencies that are often present from others that hardly ever occur in the statistics table. Therefore, the proposed application and server system would be useful for the detection of the robust high-frequency range from ambient noise, and we expect that they can be used as effective technology in the data communication and transmission field based on smart devices using high frequencies.

Finally, in future research, we will study the analysis of the threshold α analyze in relation to the propriety of the value when changed, because we only used a threshold of 5 in this paper. Moreover, because we only tested the system 3 h per day over 7 d, we need to collect more data for statistical processing and carry out more testing. Therefore, we will perform many experiments with the proposed application and server system over longer periods, and we will study statistical processing based on big data.

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