User Density Estimation System using High Frequencies in a Specific Closed Space

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***Abstract*—In this paper, we propose a user density estimation system using high frequencies and the microphone of a smart device in a specific closed space. High frequencies are sent to the closed space by the server speaker of the proposed system, and smart devices located in the space detect the high frequencies. The smart devices detecting the high frequencies send a message to the server system, and the system counts the smart devices that detected the high frequencies in the space. We tested user density with the proposed system, using 10 smart devices to evaluate performance. According to the test results, the proposed system showed 95% accuracy. The system can estimate exact user density in a specific closed space, and it can be a useful technology for protecting people's safety and measuring space use in indoor spaces.**

Keywords-high frequencies; inaudible sound; density estimation; smart device.

I. Introduction

Recently, along with the developments of Virtual Reality (VR) and Information Technology (IT), many sports services have begun to be offered, which are available in specific closed spaces, such as VR cafés, screen baseball zones, sports experience game spaces, and bowling pubs. In Korea, now, 450 screen baseball zones were built and about 50 VR cafés were opened at offline theme parks. Additionally, as a start-up item for successful businesses, affiliate stores, such as VR Playce [1] and VRIZ by YJM games [2] have been appearing regularly. Therefore, today, a great number of people go to specific closed spaces to enjoy various services, and user density estimation technologies in specific closed spaces are increasingly required to insure the safety of the service users.

User density estimation means the estimation of the number of human count in the specific space. Recent technologies for user density estimation are divided into 2 classes. The first class counts the number of people by analyzing video images or by detecting the motion vector of the people [3][4]. Others use radio devices, such as Radio Frequency Identification (RFID) tags, smart devices, sensor nodes, etc. instead of video images, and they count the number of each object for user density estimation [5][6]. However, when only one video image is used, the analysis type using video images cannot count the exact number of people, and it cannot be used in smoggy or dark spaces. Furthermore, because there are some serious issues related to personal privacy risks when video images are used, it is quite difficult to apply video image analysis for user density estimation. The first approach that uses RFID tags must supply the supplement with a RFID tag for user density estimation, and the approach that uses smart devices cannot be used in indoor spaces because of the poor signal from the smart device's Global Positioning System (GPS). Although the above technologies are suitable for outdoor and open spaces, such as subways, soccer stadiums, or baseball stadiums, they cannot be applied in specific closed spaces.

Therefore, in this paper, we propose a new user density estimation system using high frequencies via the speaker of a server system and the microphone of a smart device. The microphone of the smart device can detect an audible frequency range from 20 Hz to 22 kHz, so the smart device can detect specific high frequencies from received sounds via an application [7]. We use a widely available simple speaker for the speaker of the server system, and 2 high frequencies between 18 kHz and 22 kHz. These high frequencies are regularly used in high frequency studies, such as smart information service applications and data transmission using high frequencies; these frequencies have an important feature, which is that people cannot hear them in an indoor space [8][9]. In our system, smart devices located in the same indoor space receive sounds around each device, and the devices send a message to the server when they detect the specific high frequencies by analyzing the received sound. Thus, because the server gathers each message from the smart devices and counts the number of devices, the proposed system can estimate user density in a specific closed space. To evaluate the performance of the proposed application and server system, we developed a high frequency detection application for smart devices and a user density estimation server system, and we conducted an experiment on user density estimation using 10 smart devices. The results show that the proposed system is useful as a user density estimation technology in specific closed spaces because the accuracy of the proposed application and server system is over 95%. Therefore, as the proposed system is a new user density estimation technology using inaudible high frequencies and the microphones of smart devices, it can be a useful technology to protect people's safety in closed spaces, such as VR cafés, screen baseball zones, sports experience game spaces, etc.

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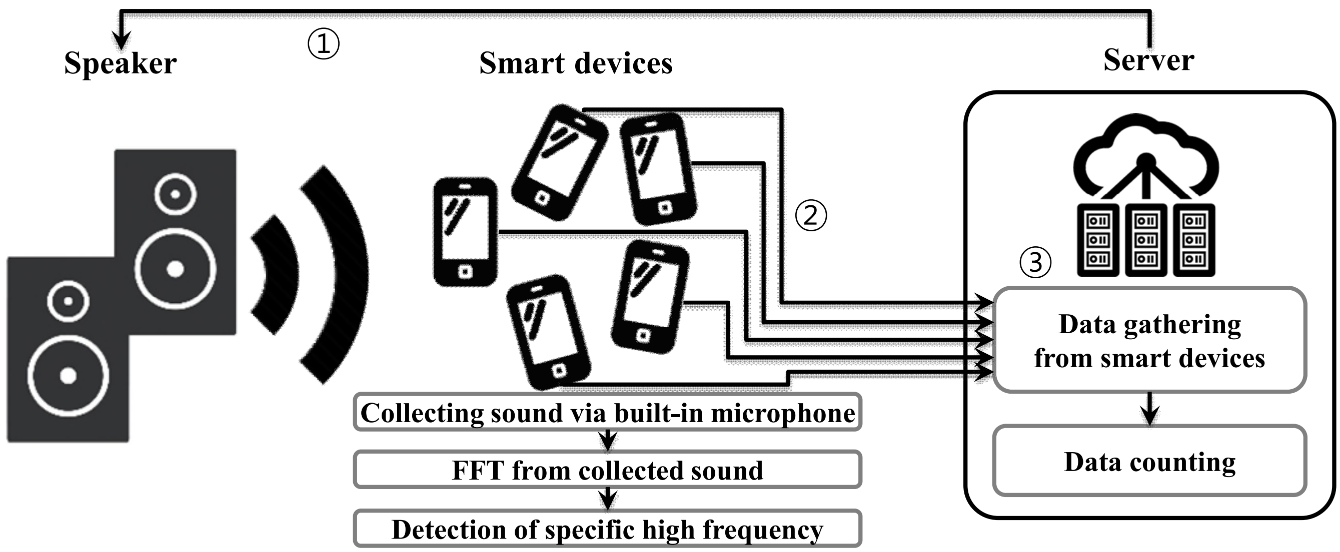

Figure 1. Total flow of the proposed application and server system.

This paper is organized as follows. In Section 2, we describe the proposed application based on smart devices and a server system. In Section 3, we describe an experiment using the proposed application and server system and discuss the results of the experiment regarding performance. Finally, in Section 4, we present the conclusions and our further research.

II. User Density Estimation System Using High Frequencies

In this section, we explain the proposed application based on smart devices and a server system for user density estimation in a specific closed space. The total flow of the proposed system is shown in Figure 1. In Figure 1, the speaker of the server system generates 1 specific pair of high frequencies (over 18 kHz) in a specific closed space over a fixed number of seconds (①), and the smart devices in the space collect the nearby sound via the microphone of each smart device. The collected sounds are converted to frequencies using Fast Fourier Transform (FFT) [10], and each smart device sends the pair of high frequencies and its own GPS information to the server system when it detects the specific pair of high frequencies over 18 kHz (②). The server gathers the data for the pair of high frequencies and the GPS information from each smart device, and then it counts the number of smart devices located in the specific closed space at the same time (③).

The specific pair of high frequencies over 18 kHz is selected as two high frequencies of 100 Hz units between 18 kHz and 22 kHz (total: 41 types of pairs). To avoid interference from other high frequencies, the interval between each high frequency is over 600 Hz. Thus, the pair of high frequencies can be composed of a total 595 types, such as 18.0 kHz–18.7 kHz, 18.0 kHz–18.8 kHz, … , 21.3 kHz–22.0 kHz. The composed pairs of high frequencies are generated by the speaker of the proposed server system and produced ***n*** times over ***k*** seconds. ***k*** is the duration of the pair of high frequencies and ***n*** is their repetition time. The produced type of pair of high frequencies is shown below in Figure 2.

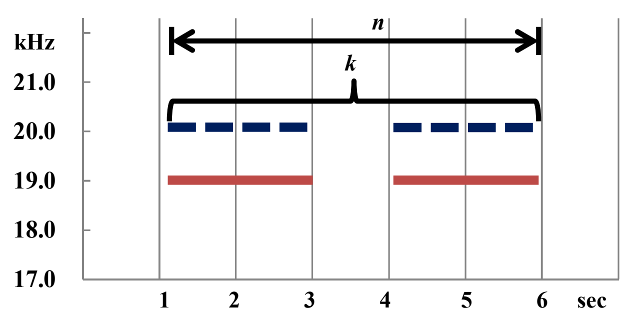

Figure 2. Example of the proposed pair of high frequencies for user density estimation.

In Figure 2, the pair of high frequencies is 19.0 kHz and 20.0 kHz, ***k*** is 5 seconds, and ***n*** is 2 times. The pair of high frequencies is generated by the speaker of the server system, and each smart device located in the specific closed space checks whether the pair of high frequencies consistently exists or not. If a smart device detects the pair of high frequencies, it waits for the fixed ***m*** seconds and detects the pair of high frequencies again to confirm that it is the same pair. Then, if the first and second pairs of high frequencies are the same, the smart device sends the pair's high frequency value and the smart device's GPS information to the server system.

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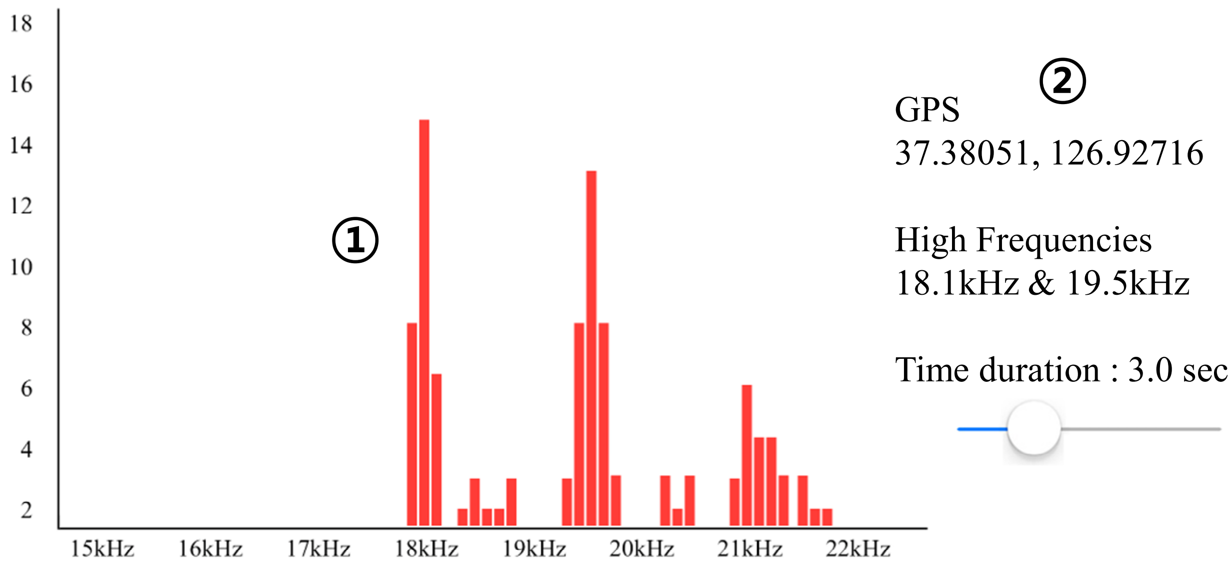

Figure 3. Screen composition of the proposed application for user density estimation.

Next, the server system confirms whether the values of the pair of high frequencies from the speaker and from the smart device are the same or not. If they are the same, the server system calculates each distance from the speaker's GPS coordinates to the smart device's GPS information. If the distance is within a critical distance (***r***) using Euclidean distance, the smart device is located in the specific closed space and the server system counts the smart device. Thus, the proposed application and server system can estimate user density in the specific closed space.

III. EXPERIMENTS AND EVALUATION

This section explains the proposed application based on smart devices for user density estimation. We describe the experiment for user density estimation and analyze the results of the experiment using the proposed application and server system. The screen composition of the proposed application is shown in Figure 3. In Figure 3, the graph located on the left-hand side of the figure shows the bin value of the high frequencies from the collected sound data, and we confirmed that 18.1 kHz and 19.5 kHz stand out among the other high frequencies. The text located on the right-hand side of Figure 3 is the smart device's GPS information, the detected pair of high frequencies, the set duration time (***k*** seconds), and the slider bar for setting duration time ***k***. In Figure 3, because we assumed that ***n*** was 2 times and ***m*** was 1 second, if we set the slider bar to 3, ***k*** is 3 seconds and the application detects the first pair of high frequencies during (***k***–1)/2 seconds. Then, the application waits for 1 second and detects the second pair of high frequencies during (***k***–1)/2 seconds again. For example, if we set 3 as ***k*** seconds, the application checks the first pair of high frequencies for 1 second, waits for 1 second, and checks the second pair of high frequencies again for 1 second.

Next, we continued the experiment using the proposed application server system. The specific closed space was a 7 × 4 m laboratory, and the speaker of the server system was located in the top corner of the laboratory, as illustrated in Figure 4. The space had a table, a hanger, four desks, and four chairs. A speaker which was named Harman Kardon Omni 20+ was located at left top corner of the space.

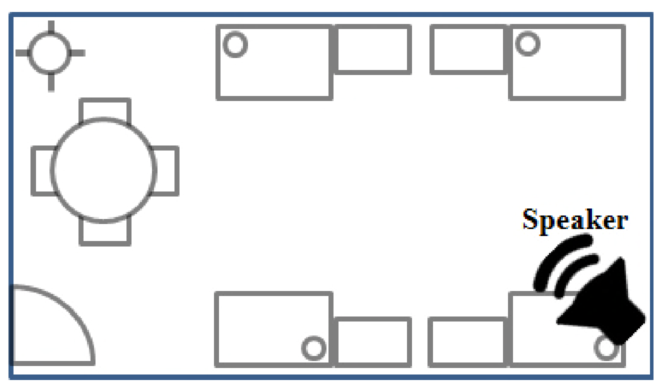

Figure 4. The floor plan of laboratory for experiment

The pair of high frequencies was 18.0 kHz and 19.0 kHz, ***k*** was 3.0 seconds, and ***m*** was 1.0 seconds. We used 10 smart devices of various models, such as iPhone 7, iPhone 6, and Galaxy s7. The server hardware was Intel(R) Core(TM) i5 CPU 750, 8G RAM, and the server environment was Apache 2.2.14, PHP 5.2.12, and MySQL 5.1.39. Each smart device was running the proposed application in background mode, and they were located in various positions around the laboratory, such as on the desk, on the chair, in the inside pocket of a jacket hung from a hanger, in front of a computer monitor, or on the floor. We generated the pair of high frequencies 100 times using the speaker of the server system

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in the laboratory; Figure 5 shows the detection results of the pair of high frequencies from each smart device.

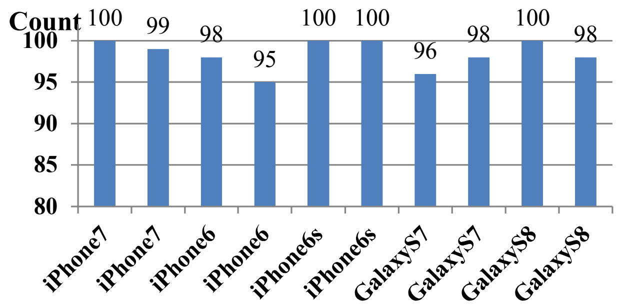

Figure 5. Detection results of the pair of high frequencies from each smart device.

In Figure 5, i7 means iPhone 7, i6 means iPhone 6, i6s means iPhone 6s, G7 means Galaxy s7, and G8 means Galaxy s8. The count does not refer to the detection number of the pair of high frequencies; it refers to the number of times a signal was sent to the server system when each smart device detected the pair of high frequencies. Most smart devices detected the pair of high frequencies over 95 times. We can see that the fourth i6 showed detection 95 times, and the seventh G7 showed detection 96 times. Because these two devices were located in the inside pocket of a jacket, we expected that these devices would have more difficulty than the others in detecting the pair of high frequencies.

Next, using Euclidean distance (***r***: 10 m), we checked the results from the server system to see whether or not all of the smart devices were located in the same place as the data from the pair of high frequencies. Because the fourth i6 and seventh G7 sent the data to the server system 95 and 96 times, respectively, the server system showed 95 times that ten smart devices were located within the same place at the same time. Thus, the proposed application and server system showed 95% accuracy from this experiment, and we believe that the proposed system can be a useful technology for user density estimation in a specific closed space.

IV. CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed a new user density estimation system using pairs of high frequencies from a server system and the microphones of smart devices. In the experiment, the server system generated the pairs of high frequencies in the specific closed space, and various smart devices detected the pairs of high frequencies and sent the frequencies' data and the smart devices' GPS data to the server system. From this process, the server system was able to count the number of smart devices located in the same space at the same time, and it was able to estimate user density in the specific closed space. Therefore, the proposed application and server system could be useful systems to estimate user density in closed spaces, and it could be a useful technology to protect user safety in closed spaces, such as VR cafés, screen baseball zones, sports experience game spaces, and bowling pubs. Because, when an emergency such as a fire occurs or building collapse, the proposed method guides to disaster relief staff the exact location of people in the closed space.

In future research, we will study a user density estimation system for multiple closed spaces in the same building and develop a visualization of the density results from multiple closed spaces from the server system. And, we will compare to our proposed method and the other user density estimation technologies using more smart devices which are moving or stopping in closed spaces such as sports game spaces, bowling pubs, and VR cafes. Moreover, we will study how the accuracy of the proposed application and server system can be improved.

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