ABSTRACT

This paper presents a system design and experimental evaluations for ambient sound-based proximity detection with smartphones. Ambient sound is useful as spatiotemporal identifier. This is because ambient sound contains abundant information which depends on time and space. To detect proximity at high accuracy, we calculate cross correlation in frequency domain for the similarity measure of ambient sound. The results of experiments show that our system discriminates 5 rooms with the accuracy of true positive 94.9% and false positive 0.1%.

Categories and Subject Descriptors
Information systems [Information systems applications]: Mobile information processing systems

General Terms
Algorithms, Experimentation, Measurement, Performance

Keywords
Ambient Sound, Proximity, Smartphone

1. INTRODUCTION

The proximity information is valuable for various applications such as analysis of human communication, indoor localization, and Social Networking Service (SNS). Compared with outdoor situations, high accurate proximity detection remains challenging in indoor situations.

Existing works use ultrasonic waves, interior illuminance, IMES, etc. These works require deploying a large amount of sensors, which make the cost of setting and maintenance high. The system based on Wi-Fi RSSI have shown the most promise. However, electromagnetic waves penetrate walls easily, which makes it difficult to discriminate adjacent rooms. Considering the location based advertising, the room-level false positive is a serious problem.

2. AMBIENT SOUND

Ambient sound consists of many sound waves which come from various sound sources. Figure 2 shows an example of the power spectrum in office environment. There are spectrums of voice, air conditioners, projectors, network hubs, etc. Ambient sound varies according to rooms, due to interference with various sound sources and sound transmission loss through walls.

In related works, similarity measure of two sound is calculated in either time domain or frequency domain. Azizyan et al. adopted similarity measure based on the Euclidean distance (EUD) in time domain [1], whereas, Tarzia et al. adopted it in frequency domain [5]. These two works rely on previously obtained sound sample in the database. To the best of our knowledge, similarity measure based on Normal-
ized Cross Correlation (NCC) [2] in frequency domain have not existed.

3. SIMILARITY MEASURE

Before calculating similarity measure of ambient sound, the power spectrum is processed to optimize. When the sound sample is uploaded, the power spectrum is divided by its median value for normalizing. The next step is computing logarithm of the power spectrum, and the power spectrum is put in the decibel (dB) scaling. In addition, to remark large power spectrum, 1 is added to the antilogarithm. Thus, the optimized ambient power spectrum $P(\omega)$ is given by

$$P(\omega) = 10 \log_{10}\left[\frac{G(\omega)}{\text{mean}(G(\omega))} + 1\right],$$

where $G(\omega)$ denotes the power spectrum.

To calculate the similarity measure between two optimized power spectrum, we use NCC coefficient. Thus, similarity measure $C_{XY}$ between user X and user Y is given by

$$C_{XY} = \frac{\sum_{w=0}^{n} (P_X(\omega)P_Y(\omega))}{\sqrt{\sum_{w=0}^{n} P^2_X(\omega)}\sqrt{\sum_{w=0}^{n} P^2_Y(\omega)}}$$

If similarity measure is larger than the threshold, users are estimated to be in proximity. The threshold is decided by experimental analysis.

4. EXPERIMENTAL EVALUATION

We conduct three experiments for evaluation of our system. Recording time length is 0.5 sec, and the sampling rate is 8 kHz. Each smartphone obtains a data set every minute.

4.1 Time-Varying Characteristic

We evaluate time-varying characteristics of ambient sound. A smartphone is located in a room, and obtains 100 data sets. Then, we calculate the similarity measure between the data sets of different times, and the results are shown in Figure 3. The similarity measures between the different time are lower than that between the same times. Hence, ambient sound has time-varying characteristics, and proximity detection by synchronized recording is more effective that by previously obtained samples in the database.

4.2 The Ability of Discriminating Rooms

We evaluate how precisely the algorithm is able to discriminate rooms. Two smartphones are located at a distance of 3.5 meters in 5 rooms. Each smartphone obtains 200 data sets. 3.5m is the boundary distance between social space and public space [3].

Using 1,000 proximity data sets and 8,000 distance data sets, Receiver Operating Characteristic (ROC) curves [4] are drawn in Figure 4, by plotting the sets of both false positive and true positive, which are given when a threshold is changed as a parameter. The evaluation using ROC curves are effective in the point of considering false positive and true positive simultaneously. The results show that the similarity measure by calculating in frequency domain is better. In addition, compared with EUD, NCC coefficient in frequency domain shows high true positive within low false positive. When false positive is 0.001, true positive is 0.949.

4.3 Influence of Distance

We evaluate how the similarity measure changes according to the distance between two smartphones. Nine smartphones are located at different distance in the same room. Each smartphone obtains 350 data sets. Figure 5 shows mean and standard deviation of the similarity measure versus the distance in two auditory scenes of two rooms. The threshold is 0.728, which gives the results in subsection 4.2. The similarity measure tends to decay with distance. The graph shows that the similarity measure is robust to detect the proximity in a short distances.

5. SUMMARY

We developed the system of ambient sound-based proximity detection with smartphones. The results of experiments show spatiotemporal variance of ambient sound, and ambient sound is a relevant source for proximity detection.

Currently, we are working on experiments in real situations. Also, we are examining the influence of microphone’s directivity and smartphone’s placement on the human body.

6. REFERENCES


