Methods and Issues in Detecting Pedestrian Flows on a Mobile Adhoc Network

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***Abstract*—Due to the development of mobile technology and adhoc communication, researches to extract social contexts including the movements and density of pedestrians have also emerged in recent years. This study attempts to explore methods to extract pedestrian flows in a distributive manner, deploying Bluetooth detection logs. Bluetooth devices are widely installed in mobile equipments which pedestrians carry with them in daily life. The results of experiments have revealed that detection logs implicitly record traces of surrounding pedestrian flows, which might provide possibilities to analyze and distinguish pedestrian flow patterns based on situations. Moreover, the paper has discussed the related issues on network construction including methods for interpolating missing detections.**

Keywords**-Distributive Database; Bluetooth; Social Context; Pedestrian Flows; Mobile Devices; Adhoc Network.***

I. Introduction

According to the increase of urban population and the expansion of social activities, we cannot avoid sharing the same public spaces with other people when traveling as well as in daily life. In any occasion, it will be one of the major concerns for people whether the area is crowded or less-crowded, and sometimes, it is necessary to know what is actually going on in such places, including the changing flow of pedestrians. On the other hand, many location-based services have appeared on market owing to the enhancement of computational ability and wireless communication technology, such as WiFi [1] and Bluetooth [2], and GPS technology [3] deployed in mobile devices. These advancements have paved way to explore methods for detecting pedestrian flows or social contexts using high performance mobile devices [4].

This research employs methods to extract the density and flows of pedestrians using the Bluetooth detection logs, while considering the data management scheme on a mobile adhoc network. This adhoc network can be generated from connection between mobile devices to work as a distributive database, which can be managed and updated the detection log data, or modified the log data by accessing to geometrically adjacent devices to check for missing detections. The policy of this work is to avoid initial preparations, such as installing a large number of expensive immovable sensors and high performance computational equipments in real space, in order to minimize cost, time and effort. In this research, we focus on the attempt to extract pedestrian flows in real world, while the specific services to utilize the detection results are left for future works.

We attempt to grasp social contexts such as changes of pedestrian flows and density by detecting the surrounding electronic equipments. Recent handheld electronic equipments like cell phone, smart phone, PDA, and laptop are installed with wireless devices such as WiFi and Bluetooth, which pedestrians carry with them in their daily lives. If these devices surrounding the user are detected and logged continuously, it may be possible to detect not only the density of crowd, but also the changes of pedestrian movements.

We have conducted a preliminary investigation to examine the statistics of detectable types of terminal (mobile phone, PC, etc.) at various places [5]. Comparing two wireless technologies, WiFi and Bluetooth, WiFi was detected from many types of electronic equipments either carried by pedestrians or fixed in the environment. Therefore, WiFi seems difficult to discriminate the types of equipments, whether they are carried by the pedestrians or not. On the other hand, by the investigation of Bluetooth signals, most of the detected Bluetooth radios were from mobile devices. In this paper, we focus on Bluetooth devices installed in equipments to be carried by users in order to examine the flows and movements of pedestrians.

To begin with, Section II provides the method of detecting pedestrian flows. The detection results obtained from actual experiment have been examined in Section III. Through the experiment, several devices were not detected within the scanning interval. Therefore, distributive and autonomous method to interpolate missing detection is discussed in Section IV and V in order to enhance further analysis of log data.

II. Detection of Pedestrian Flows

We avoid extracting the personal information of pedestrians, such as locations or user's name, since collection of such information might violate the privacy issue of pedestrians. Instead, we examine the detection patterns (e.g., numbers and changes of simultaneous or continuous detections) of devices carried by pedestrians surrounding the user. Fig. 1 shows an example of the pedestrians' Bluetooth devices which have entered the reachable communication range of

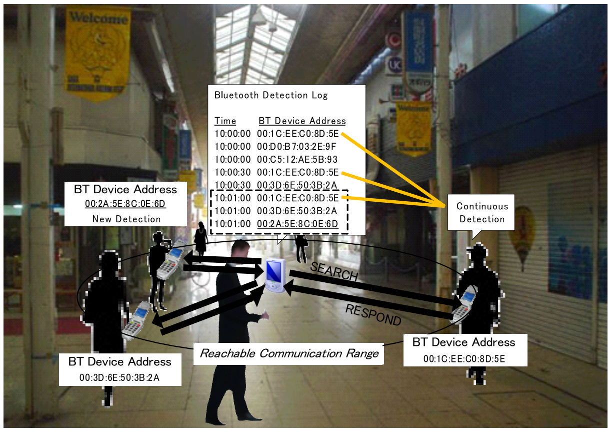


Figure 1. Detection of Pedestrian Flows

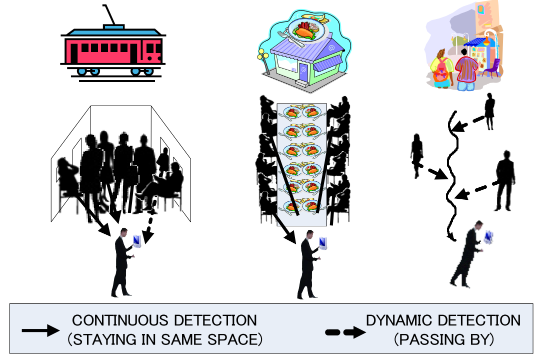


Figure 2. Detections in Different Situations

the user who is conducting the experiment. User's device continuously sends inquiry to search for the surrounding pedestrians' devices, and logs the time and Bluetooth Device Address (BDA) of devices which have responded to user's inquiry. BDA is a unique ID (MAC address) assigned to each bluetooth device during manufacture process for the purpose to identify each device. From the examination of logs, different types of detections can be verified, such as continuously detected, newly detected, undetected or disappeared, and so on, which might be the key to determine the flows of dynamic pedestrians in real world. Since the detection patterns differ depending upon the situations of the surrounding pedestrians (Fig. 2), it might be possible to assume the social contexts or trends and changes of surrounding situations by analyzing such detection patterns.

III. Verification of Detection Patterns

We have done several investigations to observe surrounding Bluetooth devices in various situations. To collect data, we used HP iPAQ 112 Classic Handheld PDA, which has been set to record BDA with a timeout interval of 6 seconds after sending inquiry signal for every 30 seconds cycle.

Four different cases have been examined in this paper, namely strolling in town, transporting by train, attending the conference, and taking lunch at a cafeteria. The results of examination of detection logs are summarized in Fig. 3. The upper diagram of Fig. 3 shows the detection pattern of Bluetooth devices, with the time-line expressed on the horizontal-axis, and the device ID assigned in chronological order of the incoming BDA on the vertical-axis. The mobile phones are colored in red, and PCs and devices other than mobile phones in green, and unidentified devices in blue. The lower diagram of Fig. 3 shows the number of detected devices, with the time-line expressed on the horizontal-axis, and the quantity of BDA on the vertical-axis.

(a) Strolling in Town: Fig. 3(a) shows the changes of multiple detection logs encountered while strolling in town. The number of BDAs is not constant as the number of passers-by is always changing. Even if the pedestrians are walking in the same direction, their devices disappeared occasionally probably because their directions coincided only for a while or their walking speed was different. On the other hand, the same BDA was continuously identified in some places while the examiner was dropping in stores.

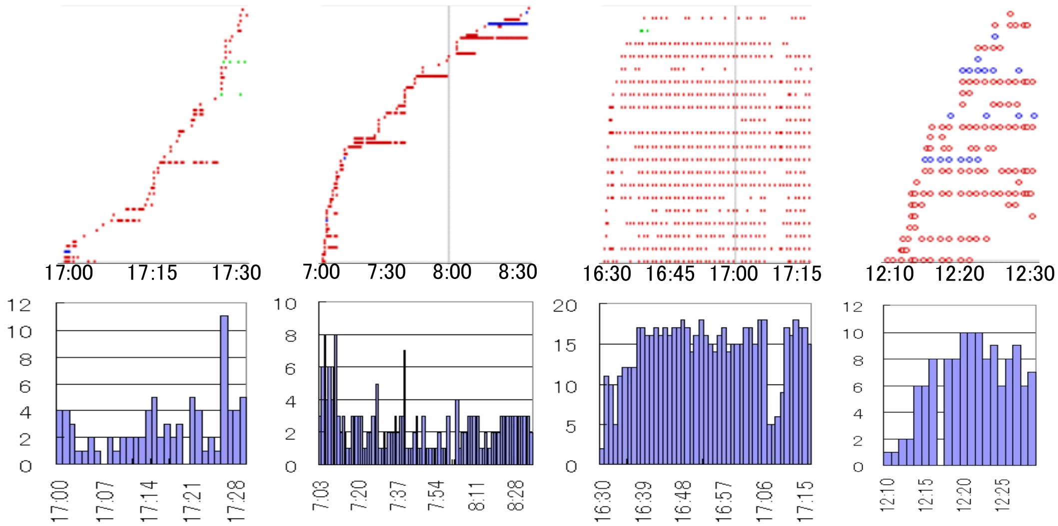
(b) Transporting by Train: Fig. 3(b) shows the detection in the train during rush hours. From the log, we can verify such situations as: (i) devices were continuously detected from passengers in the same car; (ii) many incoming and outgoing devices were detected when changing the trains; and (iii) a large number of people got on/off the train at major stations. The passenger's devices can be constantly detected while the train is moving. However, due to the limited size and shape of the car, the detection has been low even in rush hours.

(c) Attending the Conference: Fig. 3(c) shows that many BDAs were detected continuously in the same room. As most of the participants were staying in the room during the conference, the number of BDAs was almost constant (14 to 18 devices), except the time for coffee break. As the room was wide enough to hold many people, the quantity of detection has been kept high.

(d) Taking lunch at a Cafeteria: Fig. 3(d) shows that many devices have been detected during lunch time, as customers enter, take lunch and leave the cafeteria one after another. Some devices are detected continuously with long duration, and others are divided into several times with short duration, because two types of situations are mixed together: people sitting and eating lunch, and people walking around to look for seats or friends.

These results show possibilities that the pedestrian flow can be assumed by analyzing the detection logs as follows:

- **The number of BDA detection log:** crowdedness of people (requiring reference to the scale of space)
- **Time length of BDA detection:** people staying in same space or duration of the event
- **Appearance/Disappearance in BDA detection:** people staying, entering, leaving, or passing by



(a) In Town (b) On a Train (c) In a Conference Room (d) In a Cafeteria

Figure 3. Detection Pattern of BDA (upper), Detected Number of BDA (lower)

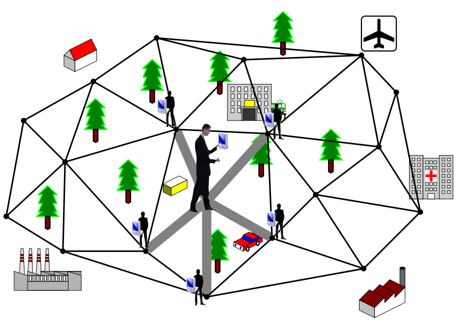


Figure 4. Delaunay Network with Mobile Devices

The detection logs show that there are several undetected devices even among those staying in the same space. Therefore, a method to interpolate the missing detection is also explored in following sections.

IV. Scheme for Distributive Data Management

Another important issue of concern is the management scheme of pedestrian flow data obtained from each mobile device. It is not efficient to collect and manage the entire data sent from mobile devices on a server. Therefore, a mechanism is necessary to manage data and perform computation between mobile devices cooperatively.

In this paper, we apply the method proposed in the past works [6] to generate P2P Delaunay network, which is a geometry-based P2P network whose topology is defined by the geometric adjacency of mobile devices as illustrated in Fig. 4. It has the features as following: (i) each device connects to a close-by devices based on its geographical distance; (ii) the degree of connection for each device is low (approximately six); (iii) the network can correspond with join/leave of device only affecting the surrounding devices to reconstruct and update the connection; and (iv) the data is reachable to distant device through multi-hop communication.

We assume that each mobile device only has the location information of other devices, but not the knowledge of how the other devices are connected. Thus, each mobile device must choose the appropriate mobile devices to connect, referring to their location information to generate a P2P Delaunay Network. The detail algorithm for generating and maintaining connections are discussed in the past works [6]. Delaunay Network can be used not only to generate or maintain connections with adjacent nodes on a plane, but also to perform collaborative computation with adjacent nodes described in the following section.

V. Interpolation of Missing Detection

There are false-negative cases that some devices within the communication range may not be detected. To deal with such problems, we consider methods to check the detection logs of adjacent nodes on Delaunay network, and interpolate the BDA data which is definitely within the communication range of Bluetooth device. Initially, each node sends a copy of its own detection logs to adjacent nodes, and receives their copy of detection logs. Then, it extracts the BDA data which is not detected from its device, but detected from other adjacent devices. These BDA data will be the target data to perform interpolation, and the location of these adjacent nodes will be the criterion to determine whether or not to perform interpolation.

We validate only the BDA data owned by more than three adjacent nodes to perform interpolation. That is, a polygon is drawn using the location of adjacent nodes with the target BDA data as vertices. If the location of its own node is within the polygon, then the target BDA data shall

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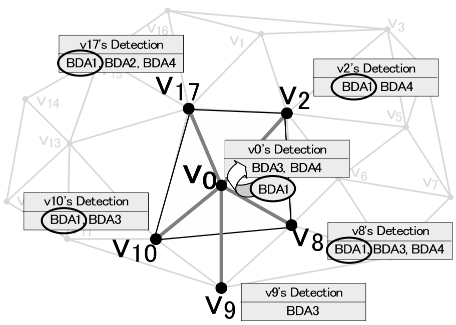

Figure 5. Interpolation of BDA Data (BDA1)

be the one to be interpolated. We chose polygonal shape to determine the interpolation, because it is obvious that the entire polygonal region is covered from the communication range of Bluetooth device. The purpose of this interpolation method is to deal with missing detection, and the deformation of communication range caused by walls, buildings, and obstacles are beyond our focus.

Fig. 5 shows the interpolation process using the Delaunay Network. Node v_0 has five adjacent neighbor nodes, namely v_1, v_2, v_3, v_4, v_5, and has the copy of their BDA detection logs. Among the BDA on detection logs, BDA1 is the only one that v_0 does not have, but more than three adjacent nodes (v_1, v_2, v_4, v_5) have. Using these nodes as vertices, a polygon is drawn starting from the upper node in clockwise direction. Finally, BDA1 can be determined to be included in v_0's detection data, as it is allocated within the polygon.

VI. Related Works

Several researches have emerged in the attempt to extract social contexts, owing to the development of mobile equipment and adhoc communication.

O' Neill et al. [7] and Nicolai et al. [8] examined the correlation between Bluetooth detecting and pedestrian movement by deploying stationary Bluetooth sensors in the environment and analyzing the logs. Eagle et al. [9] has shown methods to analyze social patterns of user's activity in a daily routine. These works show that Bluetooth scanning and analysis of detection logs have possibility to extract the flow of pedestrians, however, not every Bluetooth device can be guaranteed to be detected depending upon the performance of the device and situation of the space.

To cope with such problem, Kim et al. [10] examined the detection pattern of Bluetooth device logs, and employed clustering algorithm and Gaussian blur to remove noises caused by inquiry fault of undetected Bluetooth devices. They inferred the transition time of events from multiple device detections. Weppner et al. [11] estimated crowd density through collaboration with multiple devices to improve the accuracy of detections. Users were assigned to carry multiple devices to perform Bluetooth scanning together, which might be troublesome for users.

VII. Conclusion

We have shown possibilities to extract pedestrian flows by detecting the surrounding Bluetooth devices, and proposed to apply distributive methods to generate mobile adhoc network and manage detection data on the network cooperatively. For future works, we plan to perform detailed analysis on Bluetooth device logs, examine the applicability with other sensory data, and provide location-based application using pedestrian flows as social contexts. On the other hand, we plan to continue further study on Delaunay networks, exploring efficient ways to manage social contexts data and log files, while evaluating proposed methods to interpolate missing data caused by inquiry faults.

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