Proposing Distributive Method to Extract Pedestrian Flows on a Mobile Adhoc Network

Ryo NISHIDE† Hideyuki TAKADA‡

†Faculty of Information Science and Engineering, Ritsumeikan University

1-1-1 Noji Higashi, Kusatsu, Shiga, 525-8577 Japan

E-mail: †nishider@fc.ritsumei.ac.jp, htakada@cs.ritsumei.ac.jp

Abstract This paper explores possibilities to extract pedestrian flows from Bluetooth detection logs in a distributive manner. Bluetooth devices are installed in mobile equipments such as laptops, tablet PCs, cell phones, and PDAs, which pedestrians carry with them in daily life. If these devices can be detected and logged, it has possibilities to analyze the movements and density of surrounding pedestrians in real world. Moreover, we aim to build this system on a server-less adhoc network, in which the network can be built autonomously, and the data can be managed between mobile devices distributively. Our goal is to build this system as simple as possible, while avoiding the initial preparations to deploy sensors in real world.

Keyword Distributive Database, Bluetooth, Social Context, Pedestrian Flows, Mobile Devices, Adhoc Network

1. Introduction

In recent years, increasing number of population in the world is one of the big social problems, as we cannot avoid sharing the same public spaces with other people when travelling outdoors. These situations include transporting by train, bus, or walking, eating lunch at the restaurant, meeting at appointed place, and going to a particular site such as a historical spot, amusement park, festival and business show. In such occasions, there is a high demand of searching for crowded or less-crowded places and sometimes it is necessary to know what is actually going on in such places, including the changing flow of pedestrians. For example, though people tend to look for less-crowded places to pass by or stay, they might occasionally choose a crowded place as a popular place in some cases, considering about what is occurring there.

On the other hand, many location-based services have appeared on market owing to the enhancement of computational ability, wireless communication technology such as wifi and Bluetooth, and GPS technology deployed in mobile devices. These advancements have paved way to explore methods for detecting pedestrian flows or social activities using high performance mobile devices[1][2], and examine the applications for location-based systems such as recommendation system[3], navigation system[4], information sharing system, and so on. In most of these systems, users are not only information viewers, but also the information providers who send information as user check-in data, queue length to wait in line, user comments or evaluation of a place, and congestion information to the system, so that these information can be shared between users or applied to computation to enhance the results for recommendation system, navigation system, and so on. However, most of these systems require user to send data manually which is inconvenient for pedestrians, or collect data automatically from mobile devices which may leak their privacy information such as their device name or geographical location. Some of them require abundant initial preparations before the system can be used, which may also be inconvenient to construct a system.

This paper proposes method to extract the density and flows of pedestrians using the Bluetooth detection logs on a mobile adhoc network. This adhoc network can be generated from connection between mobile devices to work as a distributive database, which can manage and update the detection log data, or modify the log data by accessing to geometrically adjacent devices to check for missing detection. The policy of this work is to avoid initial preparation such as installing a large number of expensive immovable sensors and high performance computational equipments in real space, which can be a waste of 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.

2. Proposed Method

To build a system to extract pedestrian flow without initial preparation, two points must be considered; (i) an autonomous method to determine the movements of pe-

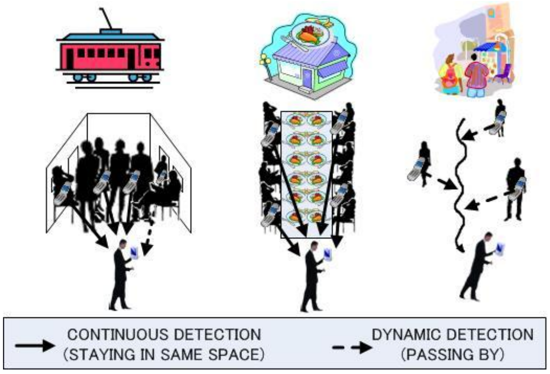


Fig 1 Detections in Different Situations

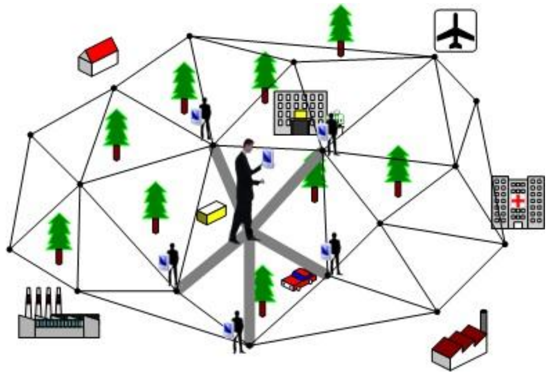


Fig 2 Delaunay Network with Mobile Devices

destrian without mounting cameras or sensors in real world, and (ii) the server-less infrastructure to maintain system and manage data on mobile devices distributively.

2.1 Extraction of Pedestrian Flows

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 has possibility to detect not only the density of crowd, but also the changes of social contexts such as the pedestrian flow. In detail, the detection pattern differs depending upon the situations of the surrounding pedestrians (Fig. 1). Thus, by analyzing the detection patterns, it might be possible to assume the social contexts or trend and changes of surrounding situation. We avoid extracting the personal information of pedestrians, such as locations or user's name, since this kind of information might violate the privacy issue of pedestrians. Instead, we examine the detection patterns (eg. numbers of simultaneous or continuous detections) of devices carried by pedestrians surrounding the user.

We have conducted a preliminary investigation to examine the statistics of detectable types of terminal (mobile phone, PC, etc.) at various places[5]. We have compared 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 identify the types of equipment, whether they are moving along with pedestrian or not. On the other hand, from the investigation of Bluetooth signals, most of the detected Bluetooth radios were from mobile devices. Especially, Softbank mobile phones were highly detected, probably because several models with Bluetooth functions were sold in Discovery mode (a configuration option to enable the surrounding terminals to discover the user's terminal) as a default setup. In this paper, we focus on Bluetooth devices since it is easier to detect the flows and movement of pedestrians, as most of these devices are installed in equipments carried by users.

We consider that our method can be performed using only the mobile device carried by user, without installing additional equipment such as mounting fixed sensors or video cameras in the environment.

2.2 Mobile Adhoc Network

Another 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.

To build such mechanism, it is necessary to construct an adhoc network using mobile devices, and utilize the network to manage the data and communicate with other devices. In this network, each device builds connection directly with other devices without communicating to the base station. To generate connection, it is important to employ an efficient scheme to choose mobile devices to connect with, considering their location and limited communicable distance of mobile devices. Note that not all surrounding pedestrians with mobile device are users to generate connection on adhoc network, considering that their device can be cell phone or device with less or no computational capability.

In this paper, we attempt to employ P2P Delaunay network, which is a geometry-based P2P network whose topology is defined by the geometric adjacency of mobile devices (Fig. 2) [6-8]. These devices are connected in a geometrical structure Delaunay Diagram well-known in computational geometry. It has the features as (i) each

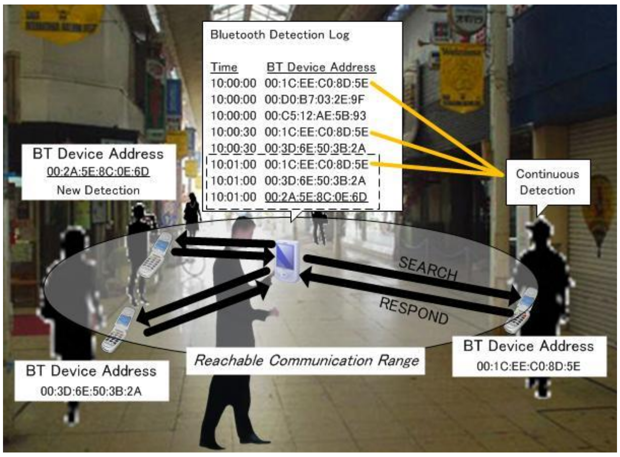


Fig 3 Detection of Pedestrian Flows

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.

P2P Delaunay Network enables to construct a networked environment in which the mobile devices are connected to each other autonomously and distributively in order to avoid preparing a server to maintain the system or manage pedestrian flow data on it. Moreover, it also provides possibilities to perform collaborative computation or processing with set of mobile devices nearby. Delaunay Network works effectively for accessing to the data in geometrically adjacent devices, which can expose the missing detection by observing at the detection logs of surrounding devices.

3. System Structure

In this section, we discuss the architect and mechanism of the system.

3.1 Detection of Surrounding Bluetooth Devices

During the manufacture process of Bluetooth device, each device is assigned with its individual ID expressed in 48-bit MAC address. This address is described as Bluetooth Device Address (BDA), and is used for communicating with other devices by sending their BDAs to identify each other. Thus, BDAs are sent constantly without requiring authentication to build connection with other Bluetooth devices. Our target is on class 2 Bluetooth devices embedded in handheld mobile equipments as cell phones, laptops, PDAs, etc, with their communication range reachable to approximately 10 meters distance. The

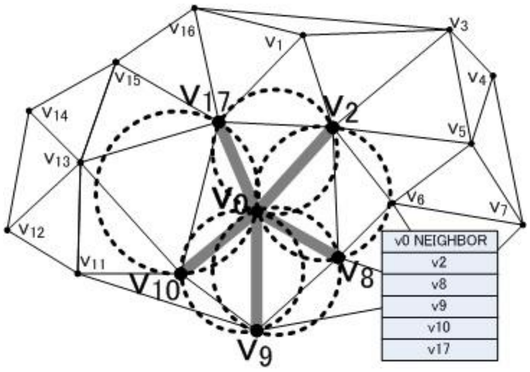


Fig 4 Determination of Nodes to Connect

protocol for the Bluetooth inquiry first receives the BDA of surrounding Bluetooth devices, and then inquires the names of these devices. A combination of BDAs and timestamps are stored in the log file for every constant time.

Figure 3 shows an example of the pedestrian's Bluetooth Device which has entered the reachable communication range of user's device. User's device continuously sends inquiry to search for the surrounding pedestrians' devices, and logs the time and BDA of devices which have responded to user's inquiry. From the log, different types of detection patterns can be verified, such as the 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.

3.2 Network Construction

In this paper, we attempt to apply the method proposed in the past works[6] to generate P2P Delaunay Network with mobile devices. 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.

To build connection of a P2P Delaunay Network under such situation, each node (referring to the geographical location of mobile device) draws an inscribed circle with two other nodes on a plane, with a property of Delaunay Network that no other nodes shall be included in the internal side of the circle. Figure 4 shows an example of v_0 determining the node to generate connection on a plane. Inscribed circles are generated connecting three nodes each, namely (v_0, v_i, v_j) $\{0 \le i \le 17, 0 \le j \le 17, i \ne j\}$, which any of these circles have no nodes in their internal. These nodes (v_2, v_8, v_9, v_{10}, v_{17}) are assigned as the neighbors of v_0 to generate connection with. If rest of the nodes (v_1 –

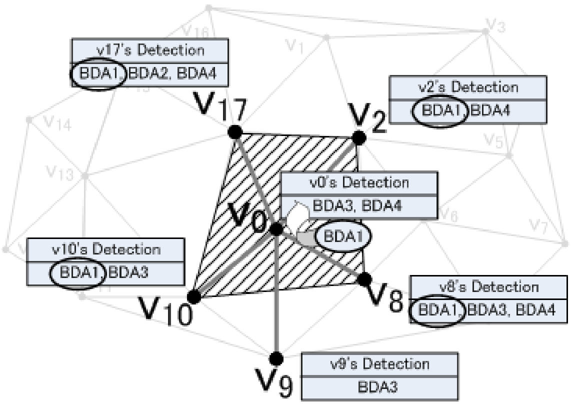


Fig 5 Interpolation of BDA Data (BDA1)

v_{17}) does these same processes v_0 has done, a Delaunay Diagram can be generated. The detail algorithm for generating and maintaining connections are discussed in the past works[6][7]. 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.

3.3 Interpolation of Missing Detection

We have described method to extract and manage the Bluetooth detection logs on an adhoc network. However, there are false-negative cases that some devices within the communication range may not be detected. That is, too many BDA data pours in at once especially at a crowded place, and the device cannot handle them all within the certain limited time interval while scanning for the surrounding Bluetooth devices.

To deal with such problem, we consider method 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 undetected from its device, but detected from other adjacent nodes' 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 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 same Delaunay Network in Fig 4. Node v_0 has five adjacent neighbor nodes, namely v_2, v_8, v_9, v_{10}, v_{17}, 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_2, v_8, v_{10}, v_{17}) 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 area.

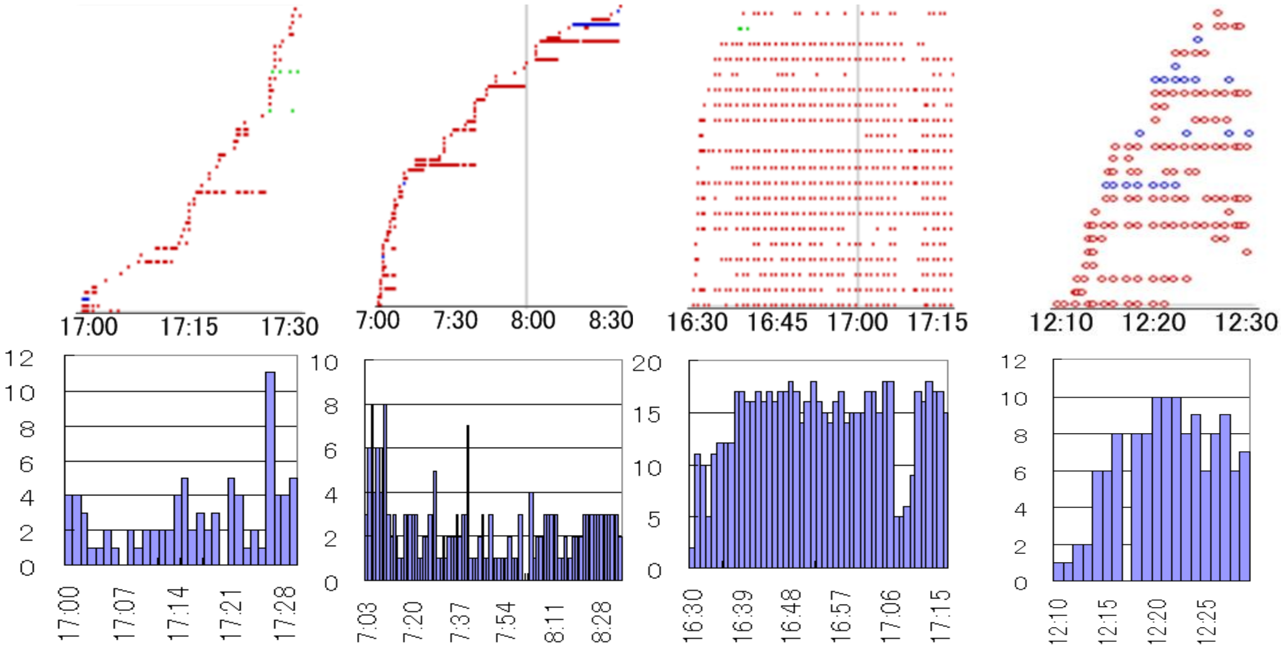
Table 1 Characteristics of Pedestrian Flow based on each Situation

		User		Surrounding ppl		Sharing Space
		Stay	Move	Stay	Move	
Town		△	○	△	○	△ or ×
Lecture room		○	×	○	×	○
Cafeteria		○	×	○	○	○ or ×
Train	Moving	×	○	×	○	○
	Staying	○	×	○	○	○ or ×

4. Verification and Discussion

The authors have done several investigations to observe surrounding Bluetooth devices in various situations, such as daily situation of working at a university, or special events as conference, sight-seeing tour, festival, and so on. To collect data, we used HP iPAQ 112 Classic Handheld PDA, which has been setup to record BDA with a timeout interval of 6 second after sending inquiry signal for every 30 seconds cycle.

Figure 6 shows BT detection logs in different situations. In this paper, four cases have been examined, namely strolling in town, transporting by train, attending the conference, and taking lunch at a cafeteria. The specific movements of user and the surrounding people are described in Table 1. The results of examination of detection logs are summarized in the points as below. The upper diagram of Fig. 6 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 the unidentified devices in blue. The lower diagram of Fig. 6 shows the number of detected devices, with the time-line expressed on the hor-



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

Fig 6 Detection Pattern of BDA (upper), Detected Number of BDA (lower)

izontal-axis, and the quantity of BDA on the vertical-axis.

(a) Strolling in Town: Fig 6(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 in only a few seconds because their directions coincide for only a few seconds and then diverge, as they stop by at a shop or change directions, or sometimes their walking speed is different. However, the same BDA was continuously identified in some places while the author was shopping or dropping in.

(b) Transporting by Train: Fig 6(b) shows transportation by 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 train; and (iii) a large number of people got on/off the train at major stations such as Osaka and Kyoto. The passenger's devices can be stably detected even if the train is moving. However, the quantity has been low even if the train is crowded because of the limited size and rectangular shape of the car. From this situation, the authors have considered that it is necessary to identify the situation from detection patterns or some other methods, as it cannot be verified from just the quantity of devices.

(c) Attending the Conference: Fig 6(c) shows that many BDAs were detected continuously in the same room. As most of the participants are staying in the room during the conference, the number of BDAs is almost constant (14 to 18 devices), except the time for coffee break. Because the room was wide enough to hold many people, the quantity of detection has been kept high.

(d) Taking lunch at the Cafeteria: Fig 6(d) shows that many devices were detected during lunch time, as customers enter, take lunch and leave the cafeteria one after another. There were many devices detected continuously with long duration or 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.

Based on the results of the experiments, the pedestrian flow can be assumed by the analysis of the data of detection log 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.

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 necessary. Moreover, the deployment of Delaunay Network and its experimentation is left for further study.

5. 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[9] and Nicolai et al[10] examined the correlation between Bluetooth detecting and pedestrian movement by deploying stationary Bluetooth sensors in the environment and analyzing the logs. Eagle et al[11] has shown method 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. For example, it may not be able to cope with too many incoming data caused by crowded pedestrians.

To cope with such problem, Kim et al[12] 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, but inquiry fault for devices cannot be detected individually. As there are many complicated situations in real world, this method may not be enough to cope with various situations. Weppner et al[13] 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.

Our research is contemplated to extract social context by scanning Bluetooth device of surrounding environments, with consideration to the user's location and the communication range of Bluetooth devices. Our method works autonomously and distributively with the users' devices on an adhoc network, which can avoid initial preparation such as installing fixed sensors or carrying multiple devices. It also enables to correspond with inquiry faults by performing computation collaboratively with nearby devices.

6. Concluding Remarks

We have shown possibilities to detect pedestrian flows by observing the surrounding Bluetooth devices, and proposed to apply method to generate mobile adhoc network and manage detection data on the network, adhering to our policy to avoid initial preparation to deploy cameras or sensors on the environment, or manage data on a one point server. Moreover, privacy issue is another concern where personal data as user name and location should not be exposed to others. For future works, we plan to perform detailed analysis and further observation of Bluetooth device logs, examine the applicability with other sensory data, and provide location-based application using social contexts as pedestrian flows. On the other hand, we plan to continue further study on Delaunay networks, explore efficient ways or possibilities to manage social contexts data and log files, and evaluate our methods to interpolate missing data caused by inquiry faults.

References

[1] P. Lukowicz, A. Pentland, A. Ferscha, “From Context Awareness to Socially Aware Computing," IEEE Pervasive Computing, 11 (1), pp.32-41, 2012.

[2] A. Campbell et al., “The Rise of People-Centric Sensing,” IEEE Internet Computing, 12 (4), pp.12–21, 2008.

[3] N. Ratipanichvong, J. Yamamoto, R. Nishide, H. Takada, “Place Recommendation for Pedestrian Reflecting Real-Time Situation and User’s Preferences”, IPSJ Symposium Kansai Branch, F-27, 2011.

[4] M. Kawabata, R. Nishide, M. Ueda, S. Ueshima, “The Context-adaptable Pedestrian Navigation System and Usability in Practical Settings”, IEEE Pacific Rim Conf. on Communications, Computers and Signal processing, 1(05CH37690), pp.368-371, 2005.

[5] R. Nishide, T. Ushikoshi, S. Nakamura, Y. Kono, “Detecting Social Contexts from Bluetooth Device Logs”, Supplemental Proc. Ubiquitous Computing (UbiComp), pp.228-230, 2009.

[6] M. Ohnishi, R. Nishide, S. Ueshima, “Incremental Construction of Delaunay Overlaid Network for Virtual Collaborative Space”, 3-rd Proc. Conf. on Creating, Connecting and Collaborating through Computing (C5'05), (IEEE CS Press), pp.77-84, 2005.

[7] M. Hirayama, M. Ohnishi, S. Ueshima, “Delaunay Network Using Detour”, Database Engineering Workshop, D7-2, 2008. (*in Japanese*)

[8] Y. Sun, Q. Jiang, M. Singhal, “An Edge-Constrained Localized Delaunay Graph for Geographic Routing in Mobile Ad Hoc and Sensor Networks”, IEEE Trans. Mob. Comput. 9(4), pp.479-490, 2010.

[9] E. O’Neill et al, “Instrumenting the city: Developing methods for observing and understanding the digital cityscape”, UbiComp, pp.315-332, 2006.

[10] T. Nicolai and H. Kenn. “About the relationship between people and discoverable bluetooth devices in urban environments”, 4th int'l conf on mobile technology, applications, and systems, pp.72-78, 2007.

[11] N. Eagle and A. Pentland. “Reality mining: sensing complex social systems”, Personal Ubiquitous Computing, 10, pp.255-268, 2006.

[12] D. Kim, D.-K. Cho, BlueSense: Detecting individuals, locations, and regular activities from Bluetooth Signals, http://urban.cens.ucla.edu/cs219/images/0/0b/BlueSense.pdf *(Retrieved March 9, 2012)*

[13] J. Weppner and P. Lukowicz, “Collaborative Crowd Density Estimation with Mobile Phones,” 9th ACM Conf. Embedded Networked Sensor Systems, 2011.