Exploring Efficient Methods to Extract Pedestrian Flows on a Mobile Adhoc Network

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***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 may be possible 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. 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 different situations. The paper has also discussed the related issues on network construction including methods to interpolate missing detections.**

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

I. Introduction

In recent years, 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 travelling outdoors as well as in daily life. These situations include such occasions as transporting by train, bus, or walking, eating lunch at restaurants, meeting at appointed places, and going to a particular site such as a historical spot, amusement park, festival and business show. In any occasions, 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. 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 spot, pondering or being curious 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 extend 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. However, most of these systems require users to send data manually, which is inconvenient for pedestrians, otherwise, collecting data automatically from mobile devices, which may leak their privacy information. Some of them require abundant initial preparations to construct the system.

This paper proposes methods 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 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 work.

To begin with, the related researches and comparable studies are reviewed in Section II. Then, the methods for extracting the density and flows of pedestrians, and the data management scheme are explained in Section III. Section IV discusses the architect and mechanism of the proposed system. In Section V, based on the results of experiments, the pedestrian flows are examined in different situations, by the analysis of detection patterns. Further study and additional experiments will be needed to cope with the interpolation of missing data and the deployment on an adhoc environment.

 ISBN: 978-1-61208-236-3

II. Related Research

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. [5] and Nicolai et al. [6] examined the correlation between Bluetooth detecting and pedestrian movement by deploying stationary Bluetooth sensors in the environment and analyzing the logs. Eagle et al. [7] have shown methods to analyze social patterns of user's activity in a daily routine. These studies 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. Thus, their methods may not be able to cope with too many incoming data caused by crowded pedestrians.

To cope with such problems, Kim et al. [8] 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. However, 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. [9] 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. The method is proposed to work autonomously and distributively with the users' devices on an adhoc network, avoiding such troubles as installing fixed sensors or carrying multiple devices. It also enables to correspond with inquiry faults by performing computation collaboratively with nearby devices.

III. Proposed Method

To build a system to extract pedestrian flow without initial preparations, two points must be considered; (i) an autonomous method to determine the movements of pedestrian without mounting cameras or sensors in real world, and (ii) the server-less infrastructure to maintain the system and manage data on mobile devices distributively.

A. 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

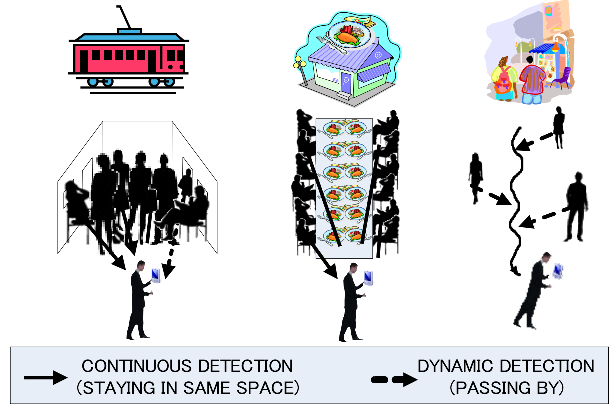

Figure 1. Detections in Different Situations

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 social contexts such as the pedestrian flow. In fact, 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 trends and changes of surrounding situations. 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 (e.g. numbers and changes 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 [10]. 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 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. 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, in order to detect the flows and movements of pedestrians, as most of Bluetooth devices are installed in equipments to be carried by users.

The method we have proposed can be performed only by utilizing the mobile device carried by the user, without installing additional equipments such as mounting fixed sensors or video cameras in the environment.

 ISBN: 978-1-61208-236-3

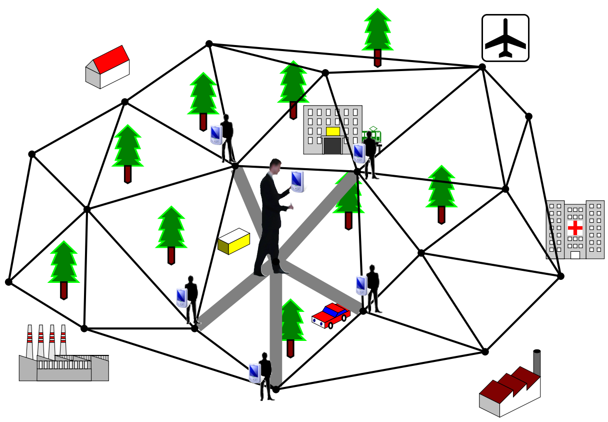

Figure 2. Delaunay Network with Mobile Devices

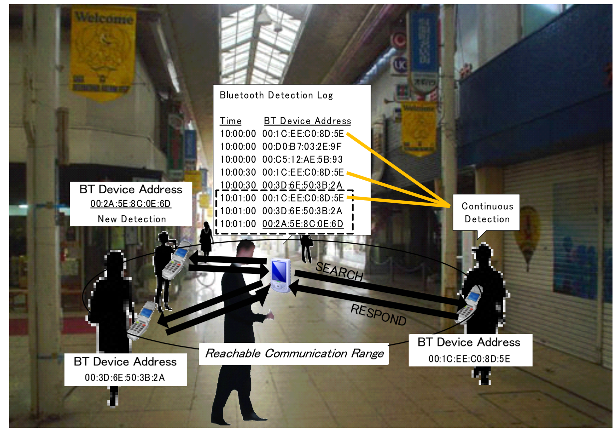

Figure 3. Detection of Pedestrian Flows

B. 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 contemplated to construct an adhoc network using mobile devices so that the network can be utilized 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. In generating connections, 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 devices are users to generate connections on adhoc network. Some of their devices can be cell phones or the kinds with less or no computational capability.

In this paper, we propose 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) [11], [12]. These devices are connected in a geometrical structure Delaunay Diagram, which is well-known in computational geometry. It has the features as (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.

P2P Delaunay Network enables to construct a networked environment in which the mobile devices are connected to each other autonomously and distributively. It is not necessary to prepare a server in order to maintain the system or manage pedestrian flow data on it. Moreover, it also provides possibilities to perform collaborative computation or processing to work 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.

IV. System Structure

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

A. Detection of Surrounding Bluetooth Devices

During the manufacturing 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 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 interval.

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 continuously detected, newly detected, undetected or disappeared, and so on, which might be the key to determine the dynamic flows of pedestrians in real world.

 ISBN: 978-1-61208-236-3

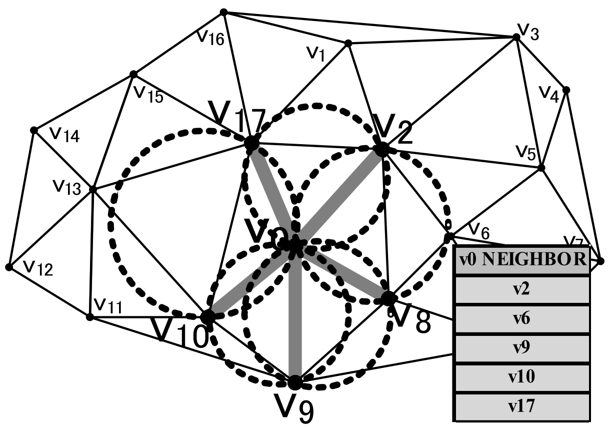

Figure 4. Determination of Nodes to Connect

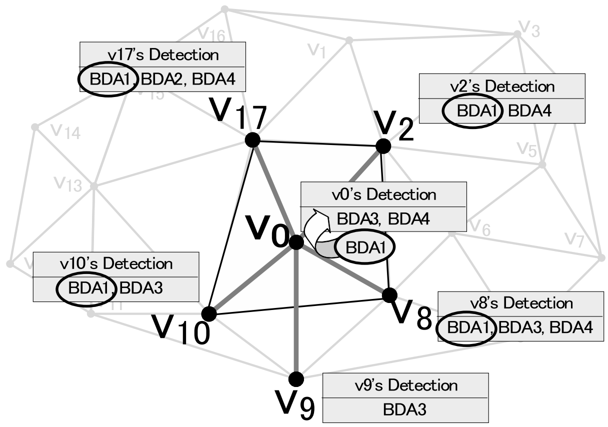

Figure 5. Interpolation of BDA Data (BDA1)

B. Network Construction

In our research, we contemplate to apply the method proposed in the past work [11] 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 connections of a P2P Delaunay Network under such situations, 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 connections on a plane. Inscribed circles are generated connecting three nodes each, namely (v_0, v_i, v_j) $\{0 \leq i \leq 17, 0 \leq j \leq 17, i \neq j\}$, which any of these circles has no nodes in the internal. The 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 - v_{17}) does the 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 work [11]. 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.

C. Interpolation of Missing Detection

We have described methods 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, abundant BDA data pours in at once especially at a crowded place, and the device cannot handle them all within the limited time interval while scanning for the surrounding Bluetooth devices.

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 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 have chosen 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 other obstacles are beyond our focus.

Figure 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.

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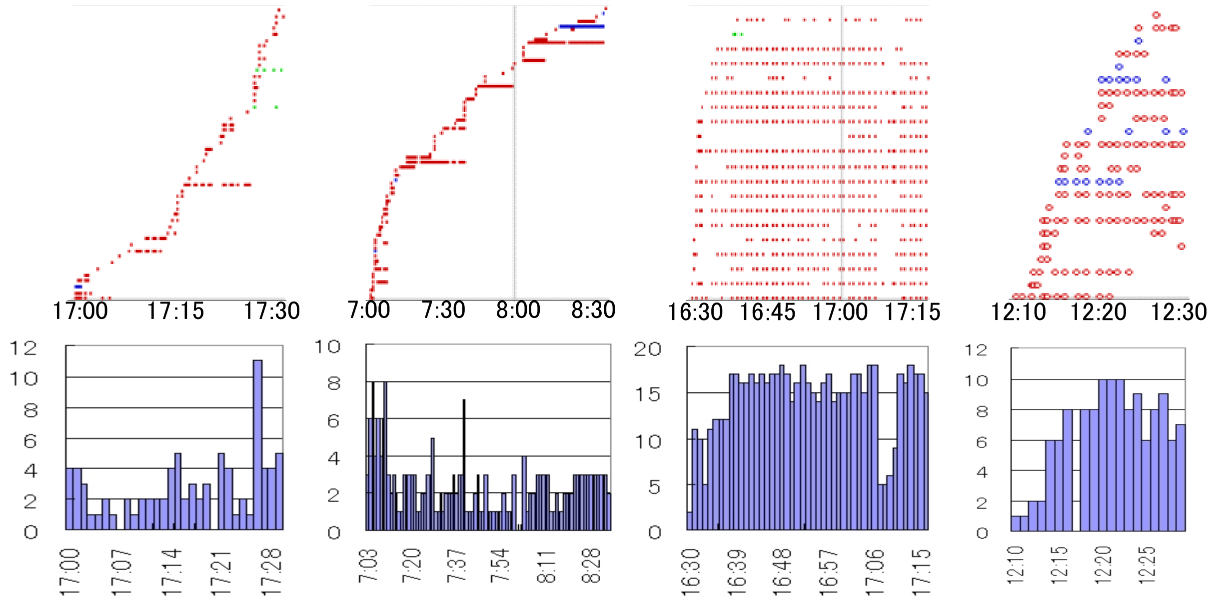

(a) In Town (b) On a Train (c) In a Conference Room (d) In a Cafeteria

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

Table I
CHARACTERISTICS OF PEDESTRIAN FLOW BY SITUATIONS

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

notations: (○)many; (△)some; (×)few/none

V. VERIFICATION AND DISCUSSION

The authors have done several investigations to observe surrounding Bluetooth devices in various situations, such as daily commuting and working at a university, or special events as conferences, 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 seconds 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 the user and the surrounding people are described in Table I. The results of examination of detection logs are summarized in the points later. 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 horizontal-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 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 user was shopping or dropping in stores.

(b) Transporting by Train: Fig. 6(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 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 continuously detected even when the train is moving. However, due to the limited size and rectangular shape of the car, the quantity of detections has been low even if the train is crowded. Because of these observations, the authors have considered that it is necessary to identify the situation from detection patterns or some other methods, as it cannot be verified merely by the quantity of devices.

(c) Attending the Conference: Fig. 6(c) shows that many BDAs were detected continuously in the same room. As

 ISBN: 978-1-61208-236-3

most of the participants are staying in the room during the conference, the number of BDAs is almost constant (counting around 14 to 18 devices), except the time for coffee break. Because the room was wide enough to hold many people, the quantity of detections has been kept high.

(d) Taking lunch at a Cafeteria: Fig. 6(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.

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

The detection logs show that there are several undetected devices even among those staying in the same space. Therefore, the interpolation of the missing detection is also needed in order to utilize the detection results.

VI. CONCLUDING REMARKS

We have shown possibilities to extract pedestrian flows by examining the detection patterns of surrounding Bluetooth devices, and proposed to apply methods to generate mobile adhoc network and manage detection data on the network, adhering to our policy to avoid initial preparations to install cameras or sensors on the environment, or manage data on a one point server. For deployment in actual environment, issues of energy consumption with mobile device battery must be considered in advancing the research. Moreover, privacy issue is also another concern because such personal data as user name and location should not be exposed to others. For future work, we plan to perform detailed analysis on 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.

ACKNOWLEDGMENT

This work was partially supported by MEXT/JSPS KAKENHI Grant Number 23650033.

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