Beacon-Based Multi-Person Activity Monitoring System for Day Care Center

Kiyoaki Komai, Manato Fujimoto, Yutaka Arakawa, Hirohiko Suwa, Yukitoshi Kashimoto, and Keiichi Yasumoto
Graduate School of Information Science, Nara Institute of Science and Technology
8916–5, Takayama, Ikoma, Nara 630–0192, JAPAN
Email: {komai.kiyoaki.kb9, manato, ara, h-suwa, yukitoshi-k, yasumoto}@is.naist.jp

***Abstract*—Recently, as elderly people population grows, the burden on caretakers are getting larger. In day care center, caretakers are taking care records aiming to improve care receiver's Quality of Life (QoL). However, in the present situation, it is difficult for caretakers to record care receiver's activity in detail because each care worker needs to take care of several care receivers at the same time and it is a large burden. To reduce the burden of caretakers, many elderly monitoring systems have been proposed so far, but most of them are not effective in the sense that they force care receivers to use dedicated device such as smart phone and/or particular applications that are obtrusive and cumbersome for care receivers. In this paper, we propose a novel elderly monitoring system which can monitor movements/activity of multiple care receivers at the same time by estimating existence area of each of the care receivers, without burdening them. Our proposed system estimates multiple care receivers existence area only using RSSI (Received Signal Strength Indication) of BLE (Bluetooth Low Energy). The feature of our proposed system is that it takes Movable-Beacon and Fixed Scanner style. We have validated the proposed system and confirmed that we can estimate multi-person's existence area at high accuracy using only BLE devices.**

I. Introduction

The number of elderly people is increasing year after year in Japan. Currently, the quarter of Japanese people are more than 65 years old. The arrival of the aging society increases the burden of staffs in hospitals and care houses. Because of the chronic shortage of caretakers, few staffs must treat many patients or residents.

This paper targets the day care center in Japan, which is a facility the local elderly people come daily. According to the investigation result [1], 1824 such centers currently exist in Japan. Each center has several tens of visitors (care receivers) in a day. Most of the centers provide transportation service. However, average number of staffs is just 3.68 person per each day care center surprisingly.

The tasks that caretakers must do are a wide variety including health check, rehabilitation support, food preparation, restroom support and conversation as shown in Fig. 1. In addition, they have to record every activity to get a financial support from the government. We visited a day care center near our university, and interviewed the manager. He said that a there are two problems with recording the activities. First problem is, of course, the increase of caretakers' work. Second is the degradation of service quality. Because caretakers use a time for documentation, they stop other burdensome tasks. For example, a rehabilitation support is quite important but the caretaker must concentrate on a certain person. If other person goes to restroom during the support, it is difficult to record it. That is, recording multi-person's activity is very hard. Therefore, the manager said that it would be helpful to record multi-person's activity if some IT systems can monitor these activities instead of caretakers.

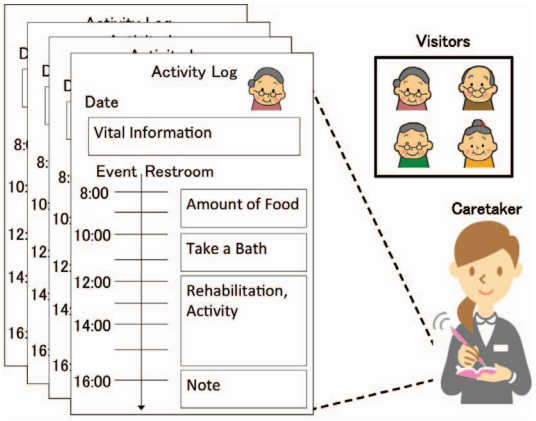


Fig. 1. Caretakers task

Based on these backgrounds, we set our ultimate goals to 1) create multi-person's activity monitoring system and 2) generate each person's activity record automatically. To achieve the above goals, we need to monitor the activities of visitors in day care center such as restroom, bath, rehabilitation and so on. In general, these activities in day care center are able to make a connect with the location information like as shown in Fig. 2. In other words, in order to create accurate activity record at day care center, it is necessary to obtain these information for each activity; when, where, who and what activity happened. Therefore, in this research, we focus on the indoor existence area estimation.

There are a lot of choices to monitor visitors indoor position, however in order to realize indoor localization in the target environment, there are three requirements as follows.

- Can distinguish from several tens of persons
- Do not require complicated operation
- Can be deployed easily with low costs

As the measurement instrument that satisfies these requirements, we adopt Bluetooth Low Energy (BLE) beacon. BLE beacon does not require any complicated operations and its cost is very low that is easy to introduce. In addition, by

978-1-5090-1941-0/16/$31.00 ©2016 IEEE

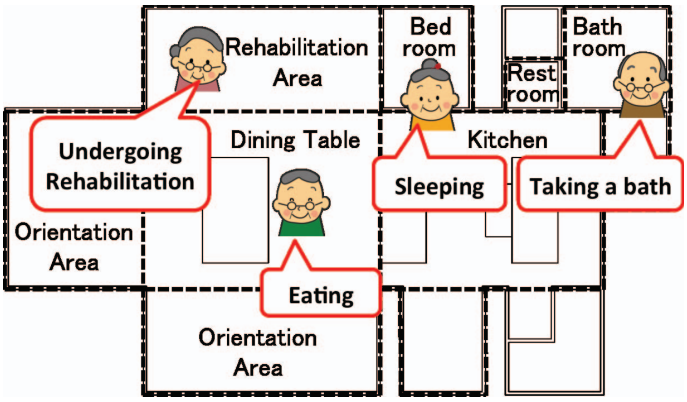


Fig. 2. Activities in day care center

monitoring its advertisement packet, we can distinguish each person. So we consider indoor localization using BLE.

In this paper, we propose a beacon-based indoor localization system that utilizes an advertisement packet transmitted from Bluetooth Low Energy (BLE) devices. The typical scenario of the related researches [2], [3] [4] and feasibility studies [5] [6] on a beacon-based localization is that many beacons are deployed in the environment and a user brings a smartphone for estimating the location by scanning the surrounding beacon signals. We can define these systems as Fixed-Beacon and Movable-Scanner (FBMS). FBMS is one of the promising method of high accurate indoor localization, but it cannot be adopted to our target environment because elderly people never bring a smartphone. On the other hand, our proposed system can be defined as Movable-Beacon and Fixed Scanner (MBFS) system, in which a beacon (BLE device) is embedded into a name card that is worn usually. In addition, some low-cost beacon scanners we developed are deployed fixedly in the target environment.

This paper is organized as follows. In Section 2, we overview some related work. In Section 3, we discuss and define the requirement of the system. Based on it, we explain our proposed system in Section 4. Some experimental results are shown in Section 5. Finally, we summarize our results and remaining works in Section 6.

II. Related work

In this section, we explain the several kind of existing research that are related to the present research. First we introduce some indoor localization method. Second, we introduce some activity recognition method. Finally we introduce BLE-based indoor localization method.

A. Indoor localization

Many researches on the indoor localization have already done Camera-based method [7] [8] and WiFi-based method [9] are one of the most famous approach in this research area. However, these are not suitable for our target environment because of the following reasons. At first, camera-based system cannot distinguish people unless the face is taken clearly. If we set several cameras on the corner of the center room, the person taken in the camera is too small to recognize the face. If we set many cameras for taking the face clearly, it requires much cost as well as violates the privacy. Secondly, WiFi-based localization system requires many access points for obtaining an accurate location. In addition, it requires the target to bring a smartphone.

B. Living activity recognition

Kasteren et al. [10] designed a system for recognizing various living activities in a smart home deploying door sensors, pressure-sensitive mats, float sensor, and temperature sensor. Chen et al. [11] designed a system for recognizing complex living activities in a smart home deploying contact, motion, tilt and pressure sensors. However, their methods require many sensors and overall system cost as well as maintenance cost will be high.

Ueda et al. [12] propose a new living activity recognition method which utilizes only power meters attached to appliances and a positioning sensor attached to a resident of a home to mitigate privacy intrusion. Additionally, they clarify that the proposed method achieved 86.9% accuracy on average for the 10 activities even in the case of a coarse sensor data granularity. However, the method supports a single resident, but does not suppose multiple residents such as a family and a day care center.

The previous studies have many problem such as 1) privacy intrusion, 2) use of many sensors, 3) many user cost, and 4) unsupported multiple residents. So, we focus on BLE device, and examine a new methods to estimate the multiple user positions used BLE device and few low cost sensors without user cost.

C. BLE Based indoor localization

Zhu et al. [2] propose the complete positioning method and a series of optimization to improve positioning accuracy, which has two phases of offline training and online locating. As a result, the method shows that the probability of locating error less than 1.5 meter is higher than 80%. However, the installation cost is high, because the method needs offline training before online locating.

Ishizuka et al. [3] conduct experimental trials in real fields an i-home trial and open beacon field trial. The results of trials show that the position estimation using BLE is not enough accuracy for position sensing of person. In the case of using only the BLE, the estimation error is 10m 20m. They discuss a hybrid localization method using pedestrian dead reckoning to increase the accuracy. However, the receiver of BLE is required calculation to that end, a high-performing product like smartphone is needed.

In these studies, many beacons are put in the environment and a user has a smartphone for estimating the location. But it is unrealistic situation because of low smartphone ownership among elderly people and the restriction that elderly people always require to wear the smartphone. In order to decrease the cost of elderly people, they should wear the receiver which is downsized and reduced weight. But it is difficult to put many smartphone in environment from the reason of high cost. So, we develop a small and low cost receiver to put in environment.

III. System Requirements and Task

In this section, we propose a new Movable-Beacon and Fixed-Scanner (MBFS) area estimation system. Our proposed system use BLE beacon and low cost BLE scanner. We describe the requirements and task when achieving proposed system.

A. System Requirements

In the day care center, the target activities are area dependent activities, for example, if visitor is in the restroom area, we can estimate that the visitor's activity is in the restroom. And if visitor is in the rehabilitation area, we think that the visitor's activity is undergoing the rehabilitation. Moreover the rehabilitation area is not small that the system need not to estimate visitors' position in high accuracy. In other words, if only the system can monitor visitors' rough staying area in and staying time, we can monitor each visitor's activity. Therefore, we define the system requirements as follows:

Requirement 1: Tracking the multiple persons
Requirement 2: Decrease persons' cost
Requirement 3: Low privacy concern
Requirement 4: Low installation cost

In order to satisfy these requirements, we adopt BLE device and MBFS system. There are three advantages compared to existing system.

First, by using BLE device, we can track multi-person with little privacy concern. Many kinds of BLE devices are designed to send advertisement packet periodically. By observing these packets, we can distinguish each person who has wearable BLE device. Moreover, BLE device is very small which can reduce a burden applied to the user. In addition, compared to existing systems which use stereo camera, this system can reduce the invasion of privacy. It satisfy the requirement 1 and 3. As we introduced in section 2, the accuracy of BLE based indoor localization system is not so good, however, in the target environment, we can estimate each visitor's activity even we could distinguish each visitor's existence area with an accuracy range of 2 or 3 meter. Therefore, BLE can satisfy the requirement.

Second, by adopting MBFS system, we can monitor the visitors existence area without requiring any complicated operation. The major system in BLE indoor localization is FBMS system. However, this system requires some operation to the users. In this research, our monitoring target is the elderly persons and the majority of them does not have smart phone and not familiar with using smart phone. Moreover, if they are forced to hold smartphone at any time in a day, they may feel nuisance. Therefore, we adopt MBFS system which the visitors does not have to do any complicated operation and the burden on holding measurement instruments also minimized. It satisfy the requirement 2.

Finally, by making low cost BLE scanner, we can drastically reduce the introduction cost. In the FBMS system, smart phone is commonly used as movable-scanner. However, in the MBFS system, it is not realistic to use smart phone as fixed-scanner. This is because putting some smart phone into large area is contrary to requirement 4. In order to solve this problem, we have made low cost BLE scanner.

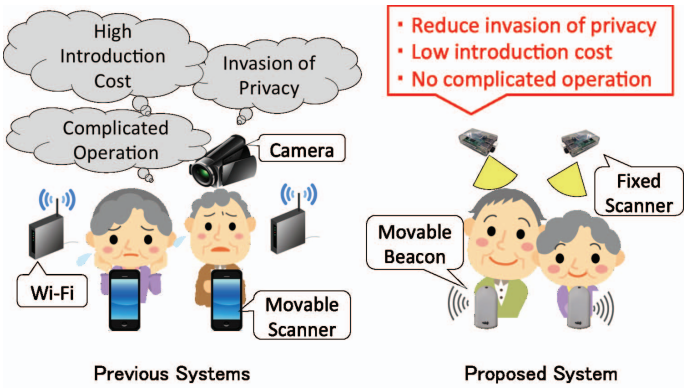


Fig. 3. Proposed system image

We install fixed-scanner to the target area where the activity we want to monitor occurs and the visitors carry BLE beacon. By comparing each scanner's RSSI, we can easily estimate their position and activity. Fig. 3 shows the proposed system image compared to previous systems.

B. Task

In order to realize the proposed system, we have to improve the area estimation rate. In the proposed system, we use RSSI to estimate multi-person's existence area, however, the value is unstable because RSSI is subject to various elements such as obstacles, temperature, reflection and so on. So we have to smooth its unstableness by using some methods. If we could put a lot of BLE scanners, we can reduce the influence of reflects and obstacles. However, installing a lot of scanners increase the installing costs, so this solution is not realistic. Therefore we have to reduce the unstableness of RSSI another way. And we focus on the feature of BLE advertisement packets. In general, BLE device advertise the packet 2 or 3 times per seconds, and by taking the average of RSSI for each person, we can reduce the unstableness of RSSI.

IV. Design of Proposed System

Based on the section 3, we design our proposed system as shown in Fig. 4. Our proposed system are consists of two function as follow: Function 1: Smoothing RSSI, Function 2: Existence Area Estimation. In this section, we explain what kind of processing is performed in each function.

Function 1: Smoothing RSSI

In proposed system, we first install BLE scanners to the environment where the target activities occurs. For example, in Fig. 4, if we want to monitor 6 activities (Rehabilitation, Sleeping, Taking a Bath, Orientation, Eating, Cooking), we have to install at least 6 BLE scanners (In Fig. 4, there are two areas which assumed to held orientation, so we have to install 7 scanners). To reduce installing costs, we have made low cost BLE scanner by using Raspberry Pi 2. And then, these BLE scanners that installed each area send scanned data (time, UUID, RSSI and installed area) to Database server. By comparing every area's RSSI value, we can estimate multi-person's existence area and activity. However, as we mentioned in section 3, the RSSI value is not stable, so we have to smooth

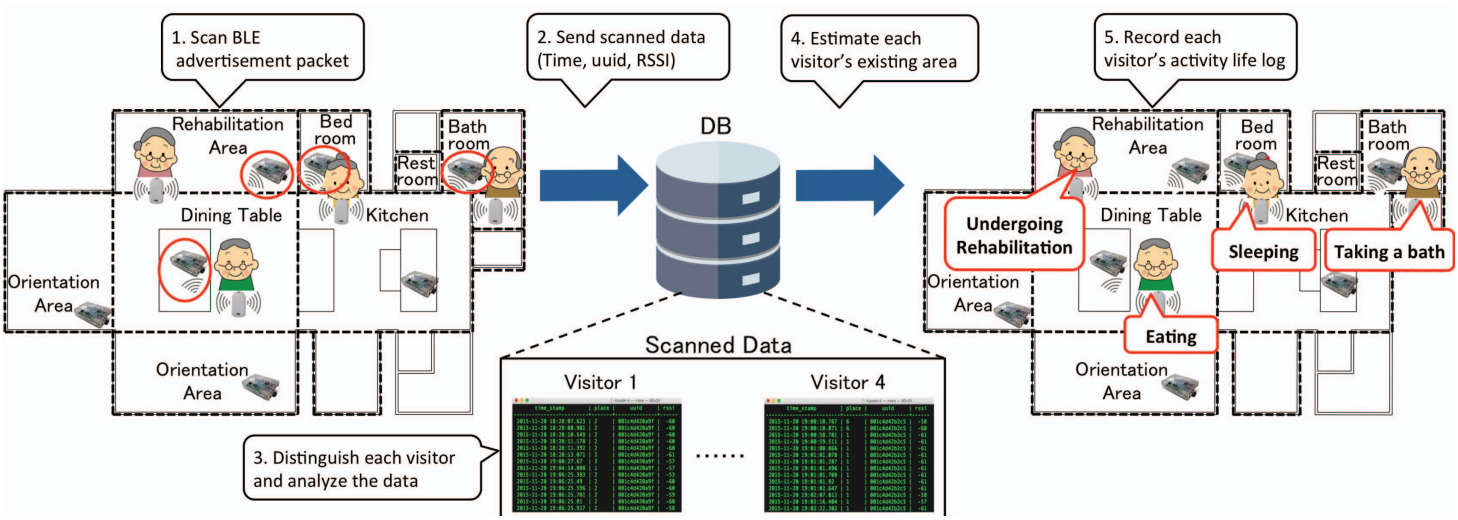


Fig. 4. Proposed System Overview

RSSI to improve the area estimation rate. To smooth RSSI, we use BLE feature that sending advertisement packet many times at short intervals (the shortest interval is 0.2 [ms] and the longest interval is 10 [s]). Moreover, the target activities (such as rehabilitation, using restroom and so on) can be regarded as special activities which require at least few minutes. Using these features, before comparing every areas RSSI value for each person, we calculate simple mean value of RSSI for each several seconds. When smoothing is held, the UUID information is used to distinguish each person.

Function 2: Existence area estimation

After smoothing, we compare each area's RSSI value for every second, and select strongest area as a existence area. As each area are associated with specific activities, we can estimate multi-person's activity. In this system, we can monitor the approximate start time and end time for each activity, however, we can't monitor the actual start time and end time. In order to make our system more practical for the caretakers, we have to improve our system. As a solution for this problem, if we could use some sensors such as human body detection sensor, electronic sensor and pressure sensor, some activities actual start time and end time can be specified. This is a subject for the future analysis.

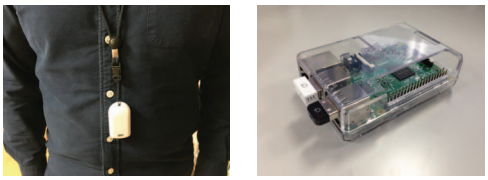
V. Experiment

In this paper, we carry out the experiment using the proposed system to evaluate the multi-person's location area estimation accuracy and show the effectiveness of our system.

A. Implementation, Environment Set up and Experimental Procedure

In the beginning, we explain the device which is used in experiments. In this study, we make a prototype of the fixed scanner and perform evaluation experiment by using commercial beacons.

As movable-beacon (sender), we use MyBeacon [13]. In the target environment, the visitors always hold name tag by



(a) BLE beacon (b) BLE scanner

Fig. 5. Beacon and Scanner

TABLE I. ACQUIRED PARAMETERS

parameter	detail
Time	Received time (in milliseconds)
UUID	Universally unique identifier
RSSI	Received Signal Strength Indicator (dBm)

hanging from their neck as shown in Fig. 5(a), so the subjects holds the beacon by hanging it from their neck like the target visitors. The beacon is very light weight and small size and does not require complicated operations. So the burden on hanging from neck and using this system are very small.

As a BLE scanner, we make a prototype of BLE scanner. In order to scan BLE advertisement packets and send the data to database server, scanner need to have two function 1) Scan BLE advertisement packet 2) Send scanned data to database server. To make the scanner, we use Raspberry Pi 2 and Bluetooth dongle (Planex BT-Micro 4) and Wi-Fi dongle (Planex GW-USNANO2A). The reason for adopting Raspberry Pi 2 as a platform of scanner is because Raspberry Pi 2 can implement these functions easily. The costs per BLE scanner are about $ 80, and very cheap compared with typical scanner such as smart phone. Table I shows the acquired parameters in experiments. These parameters can be obtained from the received signal.

Next, we explain the environment and setup in experiment. The experiment is performed at the smart home that is the experimental facility in our university. Since the high

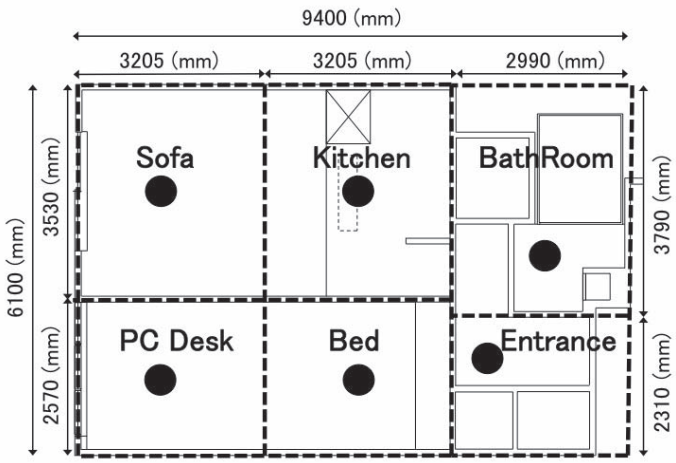


Fig. 6. Experiment environment (Black points: BLE scanner)

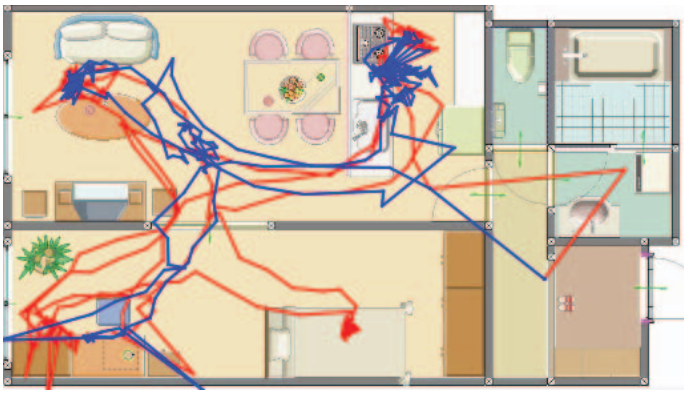
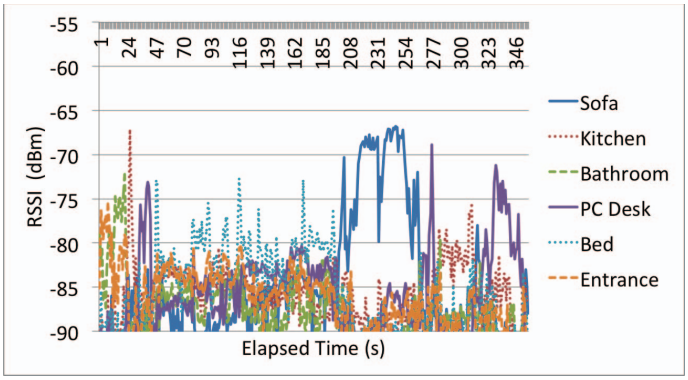
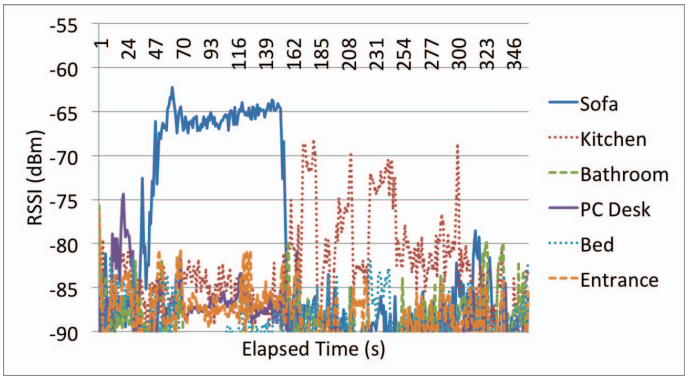


Fig. 7. Reseach subjects actual moving locus (red line: subject 1, blue line: subject 2)



(a) Subject 1 RSSI value in each areas



(b) Subject 2 RSSI value in each areas

Fig. 8. Research subjects RSSI value in each areas

accuracy position estimation system using ultrasonic and radio frequency is attached in smart home, we can collect the accurate position data easily. Hence, we use smart home as the experiment environment. Figure. 6 shows the room layout and the receiver position in the smart house. The black points in Fig. 6 represents the point where scanner are installed.

We divided the environment in Fig. 6 on the basis of location dependent activity occur, and we could divide smart house into 6 areas (Sofa, Kitchen, Bathroom, PC Desk, Bed Entrance). And then, we installed only one receiver into each area. Finally, we assigned the identifier to the divided areas.

Finally we explain the experiment scenario. In the paper, we carry out the experiment with two male research subjects. The experiment procedure is as follows. First, they wear the ultrasonic sensor to their right arm and hang the BLE beacon from their neck as shown in Fig. 5(a). Second, we instructed to the subjects to move freely at the smart home. Third, they enter to the smart home at the same time and move freely for five minutes. Finally, we compare every area's RSSI value for each subject and estimate existence area. In this section, we express two male research subjects as "subject 1" and "subject 2".

B. Results and discussions

First, we show the actual moving locus that each research subject in Fig. 7. The red line explain subject 1 moving locus, and the blue line explain subject 2 moving locus.

Next, we show the recorded RSSI value in each area in Fig. 8(a) and 8(a).

We can easily distinguish each subject by referring UUID which can be known from each beacon's advertisement packet. As shown in Fig. 8(a) and 8(b), we can estimate multi person's existence area by comparing each area's RSSI value and select the strongest one. Table II(a), II(b) shows the result when comparing each area's RSSI data for each time.

In order to evaluate our proposed system, we make confusion matrix as shown in Table II(a) and II(b). In the confusion matrix in Table II(a) and II(b), the row shows the actual areas while the columns shows the area estimated by comparing each area's RSSI value. Fig. 9(a) and 9(b) shows the correct estimate rate for each area. In Figure. 9(b), there are two X areas which means subject 2 didn't stayed these area.

As shown in Table II(a) and II(b), our proposed system can distinct multi person and estimate their existence area in high accuracy. However specific area has the very low percentage of correct estimation because of estimating neighboring areas as existence area.

It is thought that miss estimation can by reduced by taking into account of map information. As for the problems to be

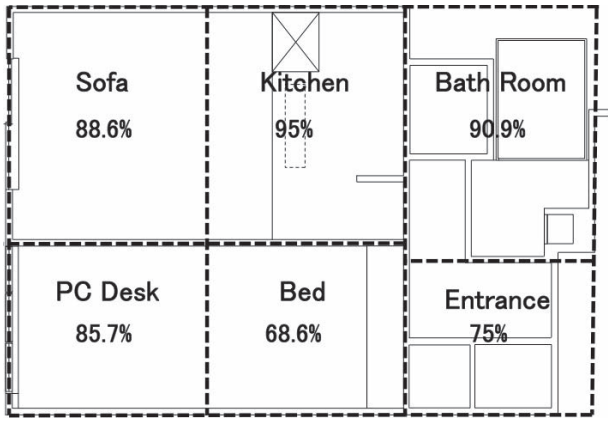
TABLE II. CONFUSION MATRIX OF TWO RESEARCH SUBJECTS

(a) Subject 1 confusion matrix

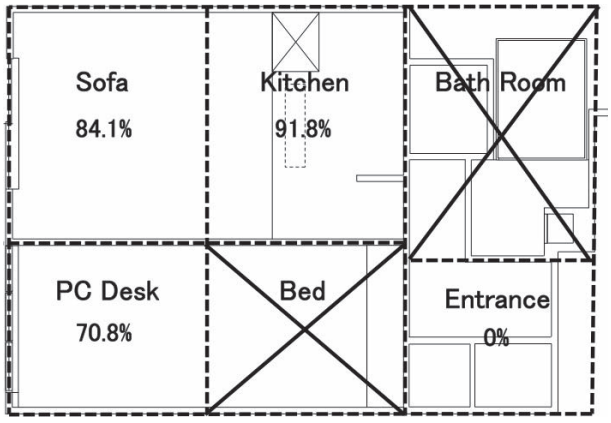
	Sofa	Kitchen	Bathroom	PC Desk	Bed	Entrance
Sofa	70	1	2	1	5	0
Kitchen	1	38	1	0	0	0
Bathroom	0	8	10	0	0	1
PC Desk	0	4	0	48	1	3
Bed	2	10	1	21	103	13
Entrance	0	0	3	0	0	9

(b) Subject 2 confusion matrix

	Sofa	Kitchen	Bathroom	PC Desk	Bed	Entrance
Sofa	138	6	16	3	1	0
Kitchen	4	147	2	0	4	3
Bathroom	0	0	0	0	0	0
PC Desk	0	3	1	17	0	0
Bed	0	0	0	0	0	0
Entrance	0	0	2	0	0	0



(a) Subject 1 correct estimate rate



(b) Subject 2 correct estimate rate

Fig. 9. Research subjects correct estimate rate

solved from now, we have to find the combination of these sensors and information and establish the way of reducing the total number of error rate.

VI. CONCLUSION

In this paper, we propose a beacon-based indoor localization system that utilizes an advertisement packet transmitted from BLE devices. The purpose of this paper is introduce this system to the Japanese-specific care house and help the caretakers without making the care receivers feel much stresses. After experimental evaluations, we found that proposed system were able to estimate multi-person's existence area by monitoring advertisement packet RSSI. As a subject for the future analysis, we have to detect actual start time and end time by combining few environment sensors such as human body detect sensor, opening/closing sensor in order to make our proposed system more practical.

ACKNOWLEDGMENTS

This work was supported by JSPS KAKENHI Grant Number 15H05708 and Strategic Priority Budget of MEXT for "Project for Promotion of Researches toward Creation of Humanophilic Science and Technology".

REFERENCES

[1] "8th national daycare center basic research statistics," "http://www.roushikyo.or.jp/contents/research/other/detail/233", accessed: 2015-11-16.

[2] Z. Jianyong, L. Haiyong, C. Zili, and L. Zhaohui, "Rssi based bluetooth low energy indoor positioning," in *Indoor Positioning and Indoor Navigation (IPIN), 2014 International Conference on*. IEEE, 2014, pp. 526–533.

[3] I. Hiroki, K. Daisuke, K. Mori, W. Takefumi, M. Shigeki, and O. Chihiro, "A fundamental study on a indoor localization method using ble signals and pdr for a smart phone sharing results of experiments in open beacon field trial," *IPSJ SIG Mobile Computing and Ubiquitous Communications Technical Reports*, vol. 2014, no. 21, pp. 1–6, may 2014, (In Japanese). [Online]. Available: http://ci.nii.ac.jp/naid/110009767733/

[4] T. Moder, P. Hafner, K. Wisiol, and M. Wieser, "3d indoor positioning with pedestrian dead reckoning and activity recognition based on bayes filtering." in *Indoor Positioning and Indoor Navigation (IPIN), 2014 International Conference on*. IEEE, 2014, pp. 717–720.

[5] "Otta," "https://www.otta.me/", accessed: 2015-11-20.

[6] "Inside Chaotic Moon Studios' Austin Offices," "http://officesnapshots.com/2014/03/10/chaotic-moon/", accessed: 2015-11-20.

[7] J. Hoey and J. J. Little, "Value-directed human behavior analysis from video using partially observable markov decision processes," *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, vol. 29, no. 7, pp. 1118–1132, 2007.

[8] L. Fiore, D. Fehr, R. Bodor, A. Drenner, G. Somasundaram, and N. Papanikolopoulos, "Multi-camera human activity monitoring," *Journal of Intelligent and Robotic Systems*, vol. 52, no. 1, pp. 5–43, 2008.

[9] A. S. Paul, E. Wan *et al.*, "Rssi-based indoor localization and tracking using sigma-point kalman smoothers," *Selected Topics in Signal Processing, IEEE Journal of*, vol. 3, no. 5, pp. 860–873, 2009.

[10] T. Van Kasteren, G. Englebienne, and B. J. Kröse, "An activity monitoring system for elderly care using generative and discriminative models," *Personal and ubiquitous computing*, vol. 14, no. 6, pp. 489–498, 2010.

[11] L. Chen, C. D. Nugent, and H. Wang, "A knowledge-driven approach to activity recognition in smart homes," *Knowledge and Data Engineering, IEEE Transactions on*, vol. 24, no. 6, pp. 961–974, 2012.

[12] K. Ueda, M. Tamai, and K. Yasumoto, "A method for recognizing living activities in homes using positioning sensor and power meters," in *Pervasive Computing and Communication Workshops (PerCom Workshops), 2015 IEEE International Conference on*. IEEE, 2015, pp. 354–359.

[13] "Applix MyBeacon," "https://www.aplix.co.jp/product/mybeacon/mb002ac/", accessed: 2015-11-20.