Indoor Positioning Method Using Proximity Bluetooth Low-Energy Beacon

Daiki Kudou
Graduate School of Software and Information Science
Iwate Prefectural University, Iwate, Japan
Tel.: (+81) 90-5834-2695, Email: g231o009@s.iwate-pu.ac.jp

Mitsuyoshi Horikawa
Graduate School of Software and Information Science
Iwate Prefectural University, Iwate, Japan
Tel.: (+81) 19- 694-2638, Email: horikawa@s.iwate-pu.ac.jp

Tatsuya Furudate
Graduate School of Software and Information Science
Iwate Prefectural University, Iwate, Japan
Email: g231n029@s.iwate-pu.ac.jp

Azuma Okamoto
Graduate School of Software and Information Science
Iwate Prefectural University, Iwate, Japan
Email: lfo@s.iwate-pu.ac.jp

Abstract. This paper presents a proposal of a practical method for use with indoor positioning systems using Received Signal Strength Indication (RSSI) of Bluetooth Low Energy (BLE) beacons. In recent years, indoor positioning methods have been anticipated for wider use in various fields such as Internet of Things (IoT) and Online to Offline (O2O). In these cases, WLAN/BLE RSSI and smartphone various sensor values have been used. Especially, great discussion has surrounded fingerprinting and triangulation methods using the BLE beacon signal strength. However, simple methods of indoor positioning systems using a proximity beacon have been advanced. In these cases, a proximity beacon determined by the RSSI threshold or RSSI comparison is used for ballpark positioning. However, calculation of the stable proximity beacon is difficult because RSSI becomes unstable in indoor environments. Therefore, we propose a low-dependence approach to the positioning environment. The proposed method consists of two steps. First, calculate the stable proximity beacon using a statistical approach. Second, calculate the location using the proximity beacon. Furthermore, a prototype indoor positioning system was developed. Experiments were conducted to evaluate the prototype system. These results suggest guidelines for the introduction of indoor positioning systems.

Keywords: internet of things, received signal strength indication, indoor navigation, online to offline

1. INTRODUCTION

Location-based systems have spread rapidly by establishment of positioning techniques using GPS. Unfortunately, GPS is not available indoors because signals cannot be detected indoors. Therefore, various indoor positioning methods have been proposed in recent years. Indoor positioning methods have been proposed such as signal strength-based methods, smartphone sensor-based methods [1–3], and hybrid methods. However, many issues remain in terms of cost and positioning accuracy. Simple methods of indoor positioning systems using a proximity beacon have been advanced. As described in this paper, a proximity beacon can be defined as the nearest beacon to the current position. Proximity beacons are used for so-called *ballpark positioning*.

As described herein, this paper propose a method for indoor positioning system using a proximity beacon and a method determined using a proximity beacon. The current study was undertaken to produce indoor location based services for smartphones. The system target is a pedestrian navigation system and online to offline (O2O) service. O2O is a new business mode combining the online shopping and the front line transactions. O2O services was often using position information because in order to combine the online and offline. O2O services have been introduced various applications such as coupon distribution based on check-in of customer and notification of nearby product information. For these applications use ballpark positioning, stability and real-time performance is needed.

2. RELATED RESEARCH

This chapter presents three methods for indoor positioning method using RSSI. Furthermore, we explained issues related to these methods.

2.1 Fingerprinting

The first method is the use of fingerprinting [4–9]. The fingerprinting method can provide value-added services for existing WLANs. Generally, the deployed fingerprinting-based positioning systems are divisible into two phases. First, in the offline phase, the location fingerprints are collected by performing a site survey of the RSSI from multiple access points. Second, in the on-line phase, a measured device of RSSI will report a sample measured vector of RSSI from different access points to a central server. The most common algorithm used to estimate the location computes the Euclidean distance between the measured RSSI vector and each fingerprint in the database. The coordinate associated with the fingerprint that provides the smallest Euclidean distance is returned as the estimate of the position. Difficulties seem to lie in their low accuracy and increased workload.

2.2 Proprietary Method

The second method is a proprietary algorithm using BLE beacons [10]. Our research group has undertaken this study. This method consists of two modules that mutually interpolate. First, it calculates the proximity to beacons using a vector space model of RSSI. Second, it calculates the pedestrian moving distance and direction using RSSI displacement. Fig. 1 presents an overview of the proprietary method by which two modules mutually interpolate their information. Our research group has introduced this method for use with transportation

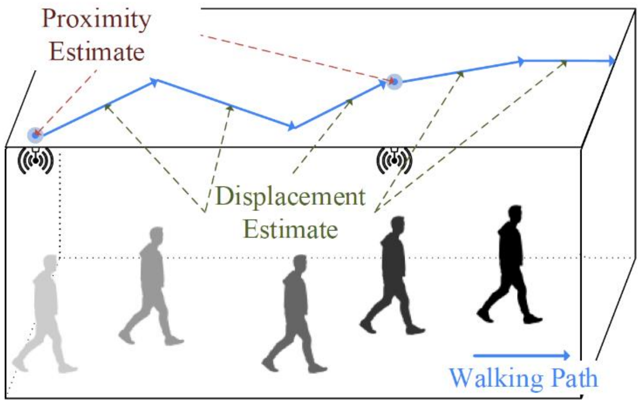

Fig. 1: Proprietary method

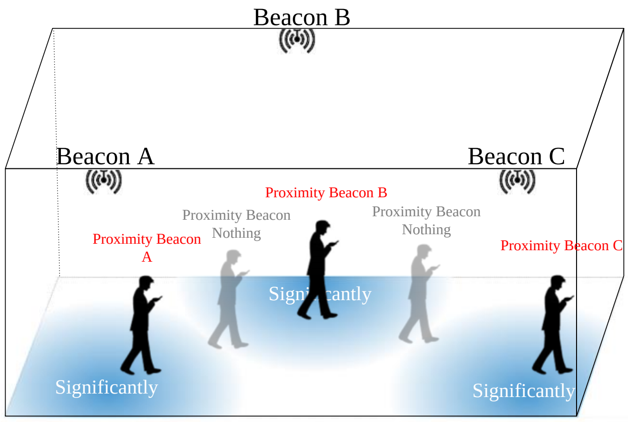

Fig. 2: Our proposed method.

infrastructure as a target. Results have shown that the placement and type of BLE beacon influence the accuracy.

2.3 Ballpark Positioning

The third method is ballpark positioning using RSSI. Generally, ballpark positioning uses a proximity beacon. In these cases, a proximity beacon is determined by a RSSI threshold or RSSI comparison. However, the calculation of a stable proximity beacon is difficult because RSSI becomes unstable in indoor environments.

3. PROPOSED POSITIONING METHOD

3.1 Prerequisite and Requirement

Following are the proposed conditions.

I. Two or more BLE beacons exist in the positioning environment.
II. The positioning device must be able to receive a BLE signal.

Table 1 Specifications of BLE250

Item	Contents
Supported OS	Bluetooth Ver. 4.0
Frequency	2402–2480 MHz
Spread system	Frequency Hopping
Output power	4dBm
Power source	DC 3 V coin battery
Current consumption	Average 30 µA
Shape Dimension	40×40×12.5 mm
Mass	About 17 g

III. The speed of the positioning target must be less than that of a human walking.

3.2 Overview of the Proposed Method

This paper describes a method of stable ballpark positioning using statistical tests. Fig. 2 presents an overview of the proposed method. The proposed method consists of two steps. First, calculate the stable proximity beacon using a statistical approach. Second, calculate the ballpark location using a proximity beacon.

3.3 Preliminary Experiments of RSSI

Generally, it is necessary to conduct suitable statistical tests to ascertain the characteristics of a statistical population. Therefore, this section performed preliminary experiments to assess the characteristics of RSSI. Experiments were conducted in an indoor environment to clarify the normality and homoscedasticity of RSSI. This section presents the experimental method and experimentally obtained results.

3.3.1 Overview of Preliminary Experiments

Experiments was performed in the indoor environment of Iwate Prefectural University. RSSI was measured when stationary and when walking. The RSSI normality and homoscedasticity were calculated using Kolmogorov–Smirnov tests and F tests. Statistical significance was assessed using 95% confidence intervals; $P<0.05$ was inferred as significant. Table 1 presents specifications of the used BLE beacons.

3.3.2 Stationary Experiment

Fig. 3 presents the stationary experiment environment. The BLE beacon was installed on the aisle. It measured the one minute RSSI at each measured point.

Fig. 4 presents the stationary experiment results. Normality was not found at all measured points. However,

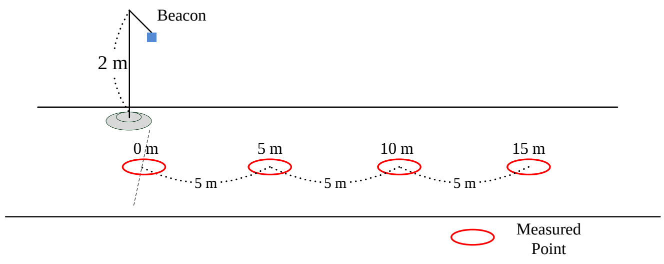

Fig. 3 Stationary experiment environment.

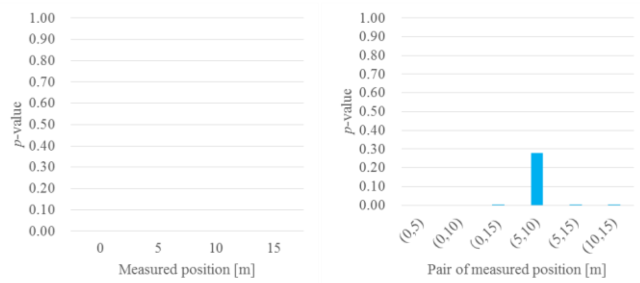

Fig. 4 Stationary experiment result.

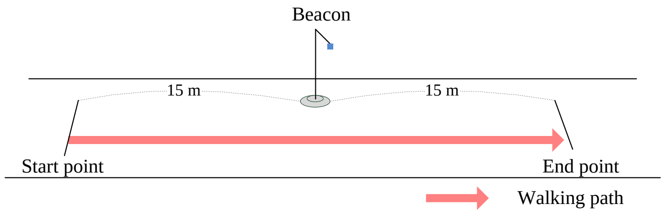

Fig. 5 Walking experiment environment.

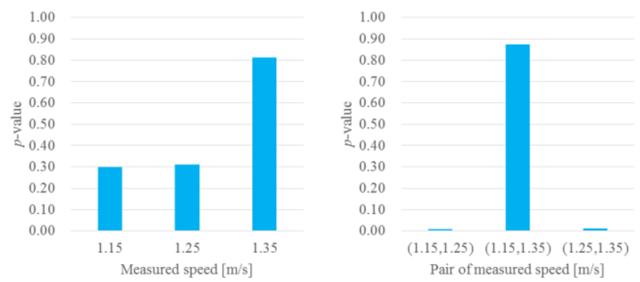

Fig. 6 Walking experiment result.

homoscedasticity is apparent only at the pair of 5 m and 10 m.

3.3.3 Walking Experiment

Fig. 5 presents the experiment environment of walking.

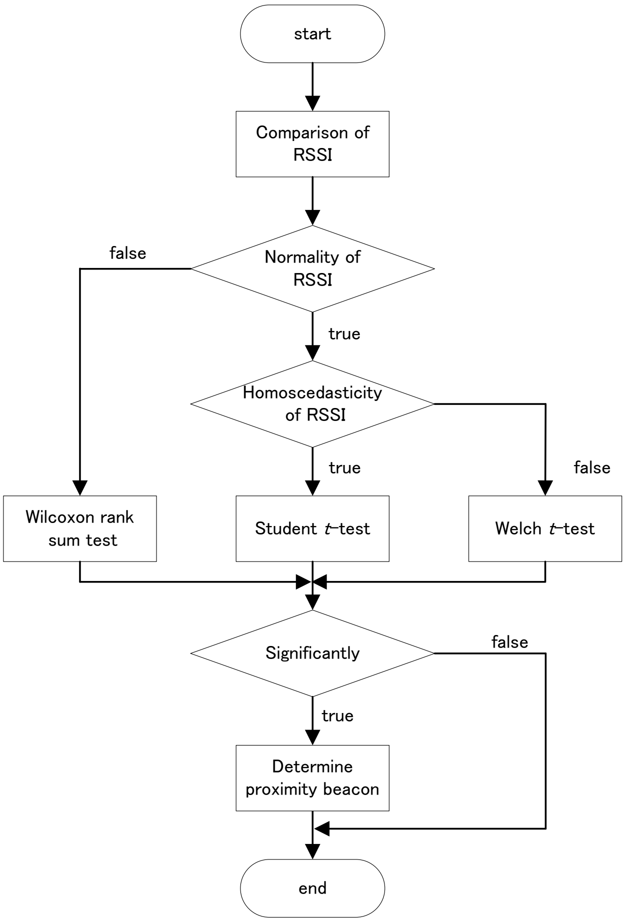

Fig. 7 Flowchart of proximity beacon determination method.

RSSI was measured during walking on the red arrow at speeds of 1.15, 1.25, and 1.35 m/s.

Fig. 6 portrays the results of walking. Normality is appeared in all experiment environment. The homoscedasticity is apparent only for the pair of 1.15 and 1.35 m/s.

3.3.4 Knowledge Obtained from the Experiment

Preliminary experiments demonstrated that the RSSI characteristics differ according to the positioning environment and the speed of the positioning target. Therefore, it is difficult to infer results solely from statistical tests.

3.4 Proximity Beacon Determination Method

Proximity beacon determination method is shown Fig. 7. It is possible to conduct suitable statistical tests for RSSI characteristics. This method comprises three steps. The proximity beacon is calculated from comparison of RSSI and results of statistical tests. Therefore, a stable result is obtained even though the measured RSSI is unstable. Steps used for this method are presented below.

Step 1: Select the BLE beacon of the statistical test

In this step, select beacons that have the strongest RSSI and the second strongest RSSI. Comparison of the RSSI used the time average of RSSI.

Step 2: Calculate the significant difference

In this step, conduct statistical tests at the selected beacons in step 1. Specifically, conduct unpaired two-tailed *t*-tests at the measured RSSI for a fixed time. The significance level influences stability and real-time performance of the proximity beacon determination method.

Step 3: Determine the proximity beacon

The proximity beacon is updated if a significant difference is found. Otherwise, the proximity beacon is not updated. Therefore, stable determination becomes possible.

Table 2 Development environment

Android System	OS	Android 4.4 or newer
	Libraries	Blereveicer-v2.2.1.0
		Google-play-services-lib
	Language	Java 7
	Developed Environment	Android Studio 2.1
Java Library	Language	Java 8
	Developed Environment	IntelliJ 2016.1.3

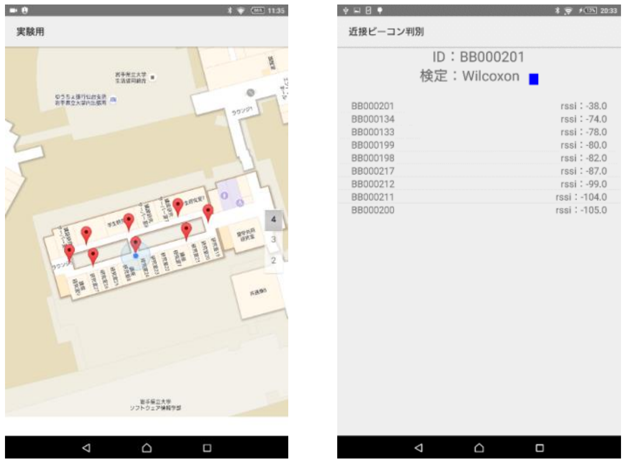

Fig. 8 Positioning screen.

Table 3 Settings for evaluation of basic performance

	Significance level	Fixed interval
Setting 1	1%	300 ms
Setting 2	1%	500 ms
Setting 3	1%	1000 ms
Setting 4	5%	500 ms

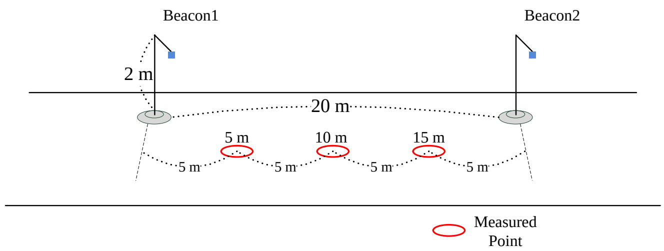

Fig. 9 Environment of stability experiment.

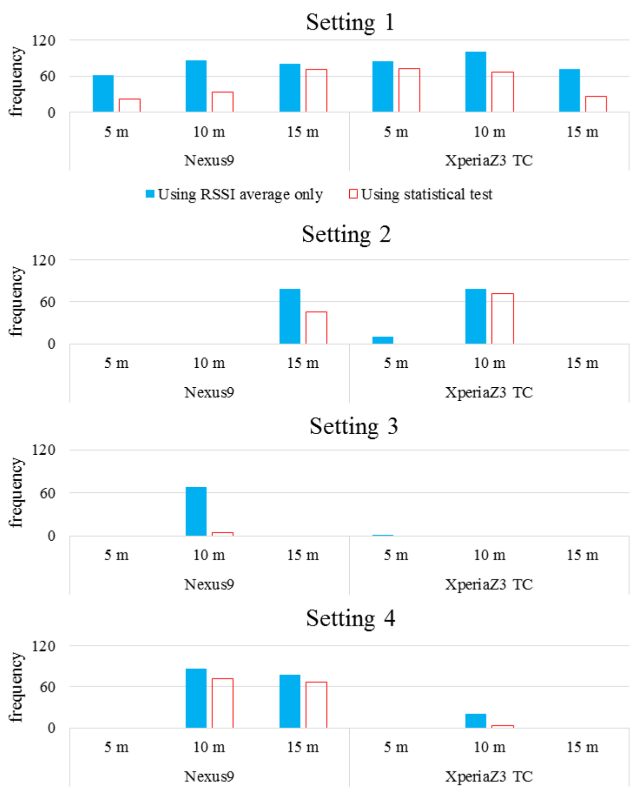

Fig. 10 Stability experiment result.

3.5 Indoor Positioning Method

This method actualizes high real-time performance by proximity beacon determination repeated with a fixed interval. Therefore, the number of RSSI used for the proximity beacon determination is changed by setting of a

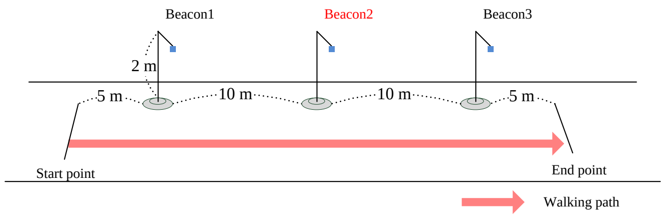

Fig. 11 Experiment environment of real-time performance

fixed interval. The statistical test accuracy is reduced in the case of a small number of samples. Therefore, setting of fixed-interval should be set as long as possible. However, the real-time performance is degraded in the case of an overly long fixed interval.

4. DEVELOPED SYSTEM

Table 2 presents the development environment. The proposed method was developed using Java. Furthermore, a prototype indoor positioning system was developed. Fig. 8 presents the positioning screen. The prototype system was developed as two types.

5. EVALUATING THE PROPOSED METHOD

5.1 Overview of Evaluation

This chapter reports the results of evaluation of the basic performance and pedestrian navigation. The evaluation of basic performance evaluated the stability and real-time performance of the proposed method. The pedestrian navigation was evaluated by assessing the accuracy determined by the proximity beacon. These experiment were used BLE beacon shown in the Table 1.

5.2 Basic Performance Evaluation

Basic performance evaluation was conducted to evaluate the stability in a stationary state and real-time performance in a walking state. Furthermore, the significance level and fixed interval were set as shown in Table 3 to clarify the influence on the fixed interval and significance level. Experiments used Nexus 9 (Android 6.0, Manufacture HTC) and XperiaZ3 TC (Android 5.0, Manufacture Sony) as positioning devices.

5.2.1 Stability Evaluation

This evaluation assessed the number of changes in the proximity beacon. Fig. 9 presents the stability experiment environment. For this experiment, the changes per 600 s were counted at each measured point. Also, results of

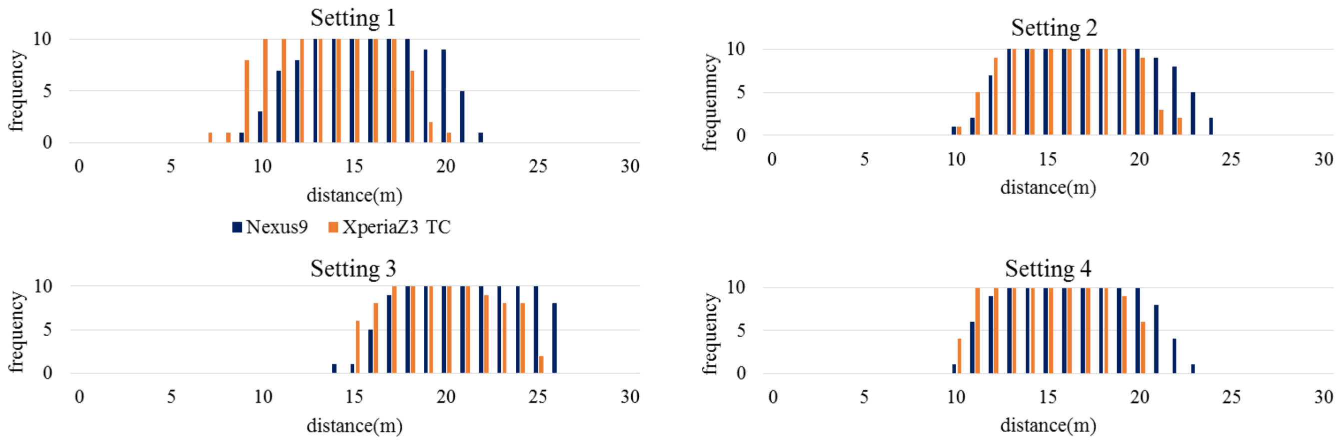

Figure 12 Evaluate result of real-time performance

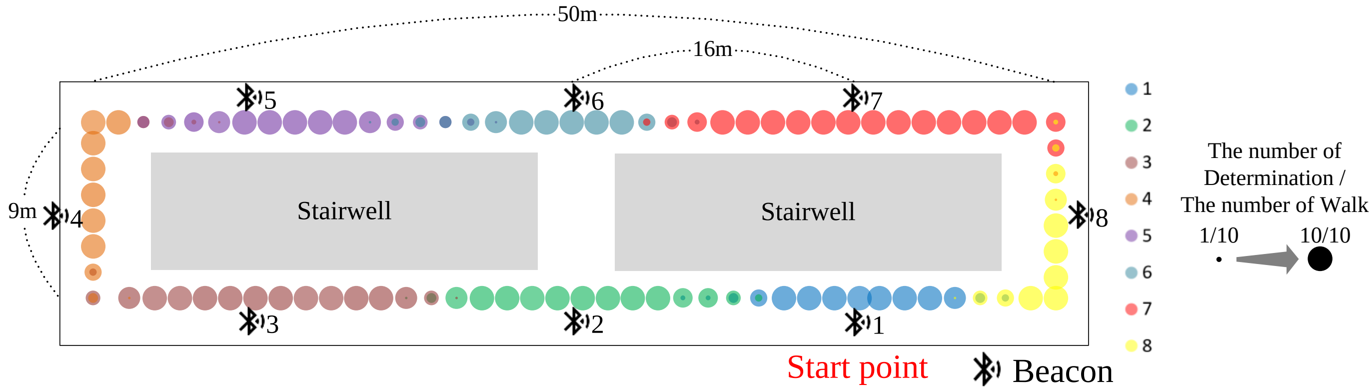

Figure 13 Evaluate result of pedestrian navigation

determination of the proximity beacon using the RSSI average were obtained for comparison.

Fig. 10 presents the number of changes in the proximity beacon at each measurement. As shown in Fig. 10, the proposed method can prevent changes in the proximity beacon. Comparison of settings 1, 2, and 3 shows that the proximity beacon determination is stabilized at a longer fixed interval. On the other hand, comparison of setting 2 and 4 shows that the influence by significance level given to stability is small.

5.2.2 Real-Time Performance Evaluation

This evaluation assessed the real-time performance of proximity beacon determination. Fig. 11 portrays the walking experiment environment. In this experiment, the arrow path is traversed 10 times at 1.25 m per second. The current position was recorded when beacon 2 was the proximity beacon.

Fig. 12 presents evaluation results. The graph shows the position at which beacon 2 became the proximity beacon. In the ideal result, the discrimination started at 10 m and ended at 20 m. In settings 1, 2, and 4, the delay was less than 2 s. However, at setting 3, the delay was greater than 3.5 s. From these results, we infer that the real-time performance is higher for a shorter fixed interval. On the other hand, comparison of setting 2 and 4 shows that the influence by significance level given to real-time performance is small.

5.3 Pedestrian Navigation Evaluation

This evaluation assessed the accuracy of determination by the proximity beacon. The experiment was conducted in an environment with eight beacons installed along the course. Fig. 13 depicts the course and placement of beacons. For this experiment, participants walked ten times clockwise from a starting point. The fixed time was set as 300 ms. The significance level was set as 1%.

Fig. 13 presents results of this evaluation. The graph shows the proximity beacon determined at each point. The discrimination results are expressed as circles of different colors for respective BLE beacons. The graph clearly shows that the proposed method is stable, with good real-time performance.

6. CONCLUSION

As described herein, we proposed an indoor positioning method using Bluetooth low-energy beacons. The proposed method, which achieved stable and high real-time performance positioning, is intended for use in an indoor positioning system, such as a pedestrian navigation and location-linked information delivery system, for which GPS is unsuitable.

The proposed method was introduced into various fields such as indoor navigation and O2O services. Future studies will consider placement of beacons and parameter settings. We hope the findings presented herein will contribute to elucidation of indoor positioning, indoor navigation, and O2O services.

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