An Application for User Indoor Movement Logs Using Bluetooth Beacons

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***Abstract*—After the launch of the Bluetooth low-energy beacon, various studies and services using the beacon have been proposed. In particular, trilateration using three or more beacons is an indoor positioning technology based on the received signal strength indicator of beacons that has high accuracy. However, this method is difficult for ordinary people to use because it requires expertise in beacon installation and positioning analysis. Thus, this study proposes an application that allows for easy installation of beacons and records user movement information in the user's home. The proposed application has the advantage of not having to accurately designate and install the beacon. The application can provide familiarity when checking user movement contents because the user can directly name the location once the beacon is installed. To verify the performance of the proposed application, we conducted an indoor movement recording experiment using beacons and the proposed application, and the experimental results showed high accuracy. Therefore, the proposed method will be a useful technology that can easily measure and record users' indoor movement information in real life.**

***Keywords*—indoor movement log, bluetooth beacon, smart application, trilateration, indoor localization, bluetooth low energy**

I. Introduction

With the increasing supply of smart devices and number of indoor positioning technologies developed, various information-providing service technologies using Bluetooth beacons have been proposed. After the launching of iBeacon in 2013, Apple installed 65 iBeacons at the MLB LA Dodgers Stadium and San Diego Petco Park Stadium to provide stadium services and club information [1, 2]. After that, SK Planet's Syrup and Yap Company's YAP provided useful information such as store discount news and coupons using beacon signals transmitted from users' smart devices [3, 4]. Most universities in South Korea also use beacon-based services as an attendance confirmation system [5, 6].

Beacons are widely applied not only to information service technology but also to indoor positioning technology. The Global Positioning System (GPS) is a widely used positioning technology, but because satellite signals are weak indoors, triangulation using the beacon's Received Signal Strength Indicator (RSSI) has been proposed [7, 8]. The RSSI refers to the signal strength of the beacon measured when the smart device receives the signal generated from the beacon, and the signal strength depends on the distance and transmission strength [9]. The RSSI value decreases as the distance between the beacon and the smart device increases, and the RSSI and distance measurement values are proportional within 4.5 m [10]. However, when the distance is more than 4.5 m, the RSSI value fluctuates owing to external factors that affect the signal, such as signal absorption, interference, and diffraction, and the signal becomes unstable, causing problems in distance measurement. Therefore, the Kalman filter is used to minimize noise and thereby increase the accuracy of the RSSI values [11]. Meanwhile, the use of moving average filters has been proposed to solve RSSI fluctuations due to external factors [12]. Liu proposed a method that combines the signal values of 10 beacons, not triangulation, to track the user's indoor movement path [13]. Concerning indoor positioning technology, users' movements and user positioning studies using triangulation algorithms are continuously conducted using Estimote Bluetooth Low Energy beacons [14], and a system has also been proposed to identify the locations of indoor personnel on naval vessels [15].

However, the existing methods have many factors to consider, such as the installation location of the beacon, calculation algorithms for tracking the user location, and the identification of interference according to indoor structures for accurate indoor positioning measurement. In addition, the beacon is difficult for ordinary people to use in identifying their location in the house and record their movement routes because accurate indoor positioning requires professional knowledge about beacon installation is required [16].

Therefore, in this paper, we propose an application that allows users to install beacons at a desired location in the house and easily set and record user movement logs in the house with the names they want. The user can install one beacon in each space according to the number of spaces set and designates the name of each space using the space name-setting menu of the proposed application. For this purpose, the installation location of the beacon is the central ceiling of the space, and when designating the name of each space, the user sets it directly under the installed beacon. After beacon installation and space name setting, the user completes the setting of the indoor

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movement log application by checking whether the space name matches within 2 m of each beacon. Next, users can use the proposed application to record their indoor movements, the time they stayed in a specific space while in the house, and their movement history through the statistical information provided by the application.

To verify the performance of the proposed application, we conducted a 2-day indoor movement record measurement experiment in a space of 60 m^2 (3 rooms, 1 living room, 1 kitchen, and 1 toilets) and a space of 84 m^2 (3 rooms, 1 living room, 1 kitchen, and 2 toilets). To measure the accuracy of the proposed application, the participant manually wrote the movement information in a notebook when moving to another space. On the basis of the experimental results from each location, we confirmed that the user movement logs of the proposed application matched 99% of the indoor movement values written by the user. Therefore, the proposed application is a useful technology that allows for easy installation of beacons in the house space, designate the space under an easy-to-understand name, and automate the user's indoor movement logs by launching only the application. In addition, the proposed method will be an excellent technology that can be applied to single-person small offices/home offices and small offices with 10 or fewer employees.

The rest of this work is organized as follows: Indoors positioning based on trilateration algorithm using Beacon signal are described in Section II. Explanation about the proposed signal processing algorithm of Bluetooth beacon and the application for user indoor movement logs through Bluetooth beacons are shown in Section III. Experimental results and discussions are shown in Section IV. Lastly, in Section V, the conclusions and establish future research directions were presented.

II. Related Work

An indoor positioning method based on trilateration algorithm using Bluetooth beacons are described here [17]. Indoor positioning technology based on Trilateration algorithm is a technology that applies triangulation method, which is used in surveying, navigation, measurement, astrometry, and rocket engineering. Triangulation method can be positioned based on the distance and angle of the two points. However, since GPS and beacon signals can only calculate straight distances, we use trilateration algorithm rather than triangulation, and we need a total of four signals for error correction.

Trilateration algorithm calculates the user's position using the linear distance from the three points. As shown in Fig. 1(a), the user location calculates the distance according to the RRSI value from each beacon by obtaining an intersection where the three circles meet, and measures the location of the point [18].

However, as shown in Fig. 1(b), if a strange signal value occurs with anchor1, we can not measure the position. This is because it is often fluctuated by the noise of the RSSI value and appears as shown in Anchor 1. To solve this problem, Yang *et al*. [19] proposed a method of obtaining an approximation using the Least square method.

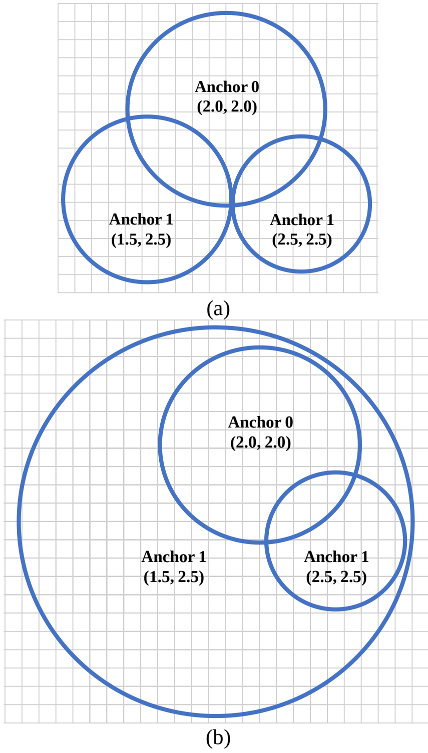


Fig. 1. An example of trilateration algorithm using signals of three beacons. (a) correct example; (b) invalid example with strange signal value.

Park installed three beacons in a space of 5×5 m and measured the indoor positioning accuracy using triangulation method [20]. And he suggested a way to remove noise once again by applying Particle Filter (PF) [21]. As a result, his proposed method achieved an error range of 2 m to 5 m, which is an error range of general Bluetooth beacon signal-based indoor positioning. However, indoor environments greatly affect RSSI values by causing multipath fading in beacon signals due to numerous reflectors such as walls, ceilings, furniture, etc. [22]. This is because the strength of the received signal is not constant even at a fixed receiving position, and acts as an obstacle to accurate indoor positioning. To solve this problem, Park *et al*. [23] proposed a method of removing and correcting highly volatile signals in advance from beacon signals affected by multiple paths and improving errors in RSSI signal-based beacon and distance calculations.

III. Application for User Indoor Movement Logs Using Bluetooth Beacons

In this section, we describe a method for calculating distances based on signals received from Bluetooth beacons and a Kalman filter for noise minimization. We also introduce a proposed user indoor movement log application for smart devices using beacon signals. The Bluetooth beacon continuously generates RSSI signals and transmits a specific ID value to the smart device. The larger the RSSI signal value, the stronger the signal strength, and we can infer that if the RSSI signal value increases, the distance between the smart device and the beacon becomes closer. The RSSI signal and distance measurements using RSSI signal values are shown in Eqs. (1) and (2) [24].

$$\text{RSSI} = -10n\,log(d) + \text{Tx Power} \quad (1)$$

$$d = 10^{\frac{(T_x\,Power - RSSI)}{10 \times n}} \quad (2)$$

Eq. (1) describes how a beacon transmits a Bluetooth signal via transmit power and shows how a smart device within the beacon signal range determines the power of the RSSI signals from the beacon. In Eq. (2), the distance between the beacon and the smart device is calculated. As a unit of *RSSI*, the *dBm* value is power expressed in *mW* on a *dB* scale. If *dBm* value is closer to zero, the distance between the beacon and the smart device is shorter; if the negative value increases, the distance between the beacon and the smart device is greater. However, the farther away the RSSI signal is from the beacon, the noisier it becomes, making its value often inconsistent. As the beacon signal is unstable because of external factors at a distance of 4.5 m or more, errors often occur in the distance value between the beacon and the smart device. To solve this problem, Wouter proposed the use of a Kalman filter and conducted experiments regarding the use of this application [25]. The transition matrix A_k is set to an identity matrix, and there is no control, the control matrix B_k is set to zero. As the state is modeled directly, the observation matrix H_k is also set to identity. Therefore, the transition and observation model can be turned down to :

$$x_k = A_k x_{k-1} + B_k uk + w_k = x_{k-1} + w_k \quad (3)$$

$$z_k = H_k x_k + v_k = x_k + v_k \quad (4)$$

w_k and v_k describe Gaussian noise. The prediction of the Kalman Filter is Eqs. (5) and (6).

$$\hat{x}_{k|k-1} = \hat{x}_{k-1|k-1} \quad (5)$$

$$P_{k|k-1} = P_{k-1|k-1} + R_k \quad (6)$$

R_k is the process noise which is set to a small value (0.008). The Kalman gain is computed as Eq. (7).

$$K_k = P_{k|k-1}(P_{k-1|k-1}Q_k)^{-1} \quad (7)$$

In Eq. (7), Q_k is the measurement noise which is set to the variance of the measurements. The final update is Eqs. (8) and (9).

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k(\hat{x}_{k|k-1} - z_k) \quad (8)$$

$$P_{k|k} = (1 - K_k)P_{k|k-1} \quad (9)$$

To demonstrate the effectiveness of Kalman Filter, Wouter showed that using the Kalman filter could reduce the noise at a distance of 1 m.

Next, the signal sent by the beacon transmits not only *Tx Power* but also various information such as the name of the designated beacon, manufacturer name, model name, and universally unique identifiers. The user can then change the name of the beacon using a beacon-setting application such as BeaconSET or LightBlue, and the *Tx Power* intensity and broadcasting interval can also be changed. However, in this study, nonprofessional users did not use beacon-setting applications; instead, they used preset values without modifications. In addition, the users set the nickname of the beacon installed indoors using the proposed indoor movement log application, as shown in Fig. 2. To set the beacon's nickname, the user should be located directly below the place where the beacon is installed. The application displays the beacon closest to the user at the top of the list on the screen, and the user touches the right + icon of the beacon name shown at the top of Fig. 2(a). When the window for setting the beacon's nickname appears in Fig. 2(b), the user enters the alias "Living room" for that location and chooses "OK." The application sets the alias of the nearest beacon to "Living Room" in Fig. 2(c), and the user would use the pen icon to change the alias later in Fig. 2(d). In Fig. 2, MiniBeacon_32767, MiniBeacon_32768, and MiniBeacon_32769 are marked "No name" because the user has not yet set the alias. On the other hand, MiniBeacon_32770 is "Kitchen" and MiniBeacon_32765 is "Room 1," which are the aliases set by the user. The proposed application does not provide on the list all the beacons located around the user and only displays beacon signals with information consistent with "MiniBeacon" by checking the first 10 digits of the initial set name on the beacon. When users install the beacons in each location they want and completes the alias designation, the application records and displays the time the user stays in the location after moving inside the home, as shown in Fig. 3.

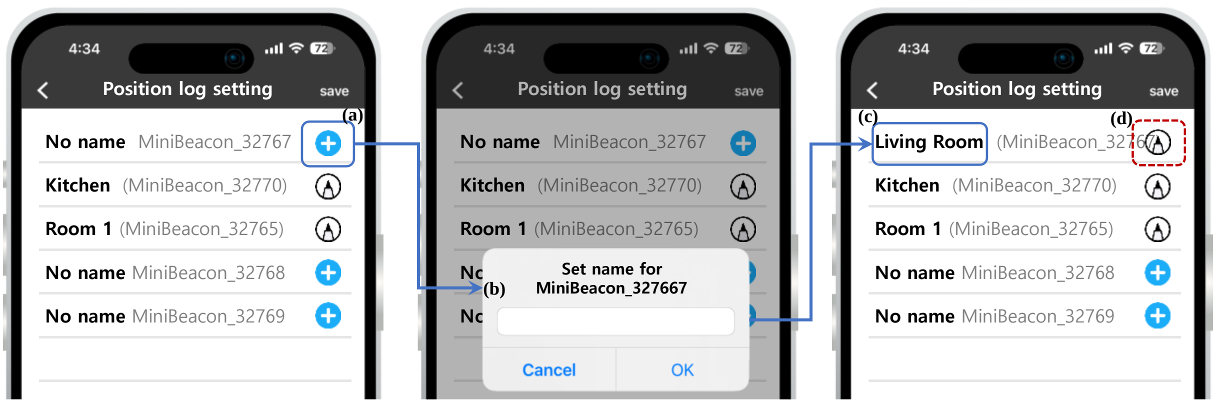


Fig. 2. Setting a nickname for the beacon in the house using the proposed application.

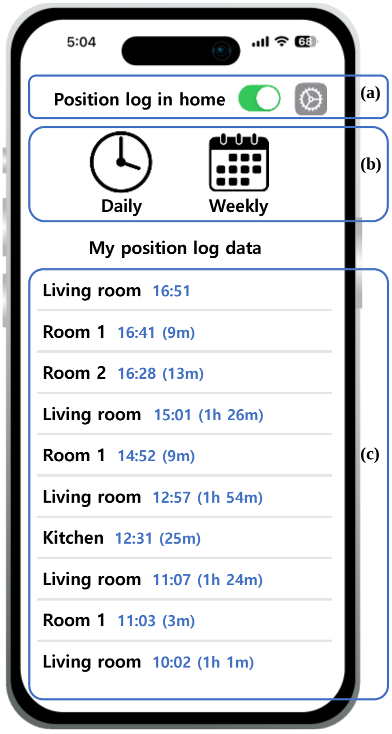


Fig. 3. Screenshot of the proposed application for storing user movement logs in the home.

In Fig. 3(a) has a switch to start or stop storing the user's movement locations, and there is a setting icon to go to the setting screen in Fig. 2. Fig. 3(b) has menu buttons that show the user's daily and weekly location statistics. Fig. 3(c) displays information the user's locations on a specific day, and the times the user first entered and exited the location in the latest order. Fig. 3 shows that the user is currently in the living room since 16:51, and before that, he was in Room 1 for 9 min from 16:41. The proposed application uses the SQLite database engine to store user movement locations and staying information because it does not require a server, can be stored on personal smart devices, and can be easily set up. The user movement location and staying information stored using SQLite of the proposed application is shown in Table I.

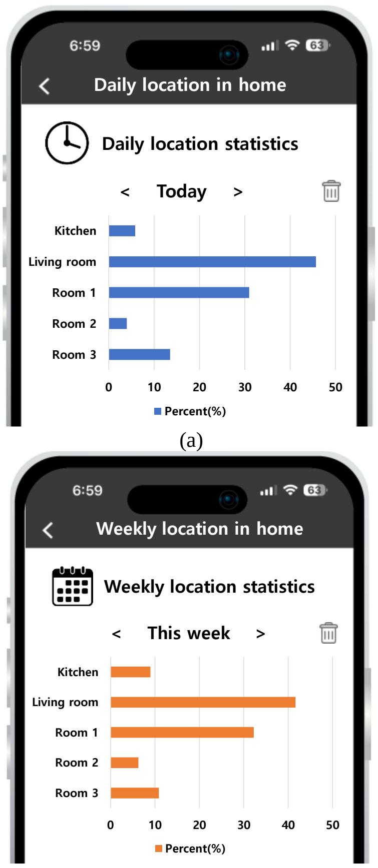
TABLE I. SQLite Data Scheme and Real User Movement Log Data Generated by the Proposed Application

Index	Location	Start time	End time	Spend time
760	Living room	1696751486	0	0
759	Room 1	1696750893	1696751486	9
758	Room 2	1696750085	1696750893	13
757	Living room	1696744891	1696750085	86
756	Room 1	1696744333	1696744891	9

In Table I, the table schema of the SQLite database consists of index, location, start time, end time, and spend time. Index is the number of the order in which data are stored; location shows the alias of the space where the user is currently located; start time shows the time the user first entered the space; end time indicates the time the user left the space; and spend time shows the duration of the users' stay in the space.

The start time and end time are stored in the form of a timestamp that displays the time elapsed from 0:0:0 on January 1, 1970 GMT. This data format allows for easily obtaining daily and weekly statistics for the proposed application, and the stored SQLite data are the daily and weekly statistics as shown in Fig. 4(b) through the menu in Fig. 3. As shown in Fig. 4, the user set a total of five moving spaces: Kitchen, Living Room, Room 1, Room 2, and Room 3. Fig. 4(a) shows the daily statistics from the user's indoor movement logs, and the time spent in each of the five spaces is summed, calculated by ratio, and expressed as a graph. Fig. 4(b) shows the user's weekly statistics for 7 days, from Monday to Sunday, and the ratio is calculated and expressed as a graph after summing the time spent in each space in the same way as the daily statistics.

Finally, there is a problem when the RSSI from two beacons is nearly identical, because the user is located at the center or edge of the room. This problem occurs in three cases. First, because RSSI weaken as they pass through the wall, this problem can sometimes occur when users are located away from the center of the beacon location and on the wall side of the room where other beacons are installed. Second, it is a case where the user is located in the center of the door between the room and the room. Third, although the user is located in the center between the beacon and the beacon, this does not occur frequently. Therefore, to solve this problem, we applied a moving average filter when the application has the same value of beacon signal as in the above cases [26].

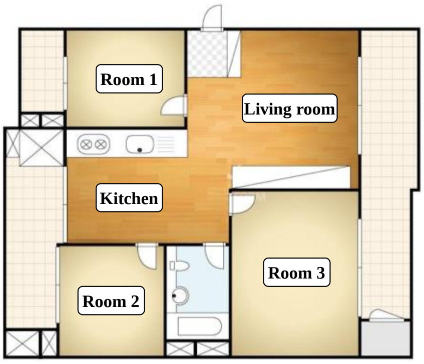


(b)

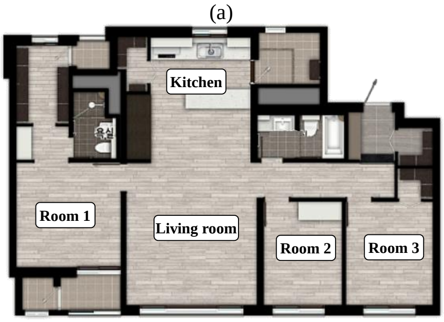
Fig. 4. Screenshot of the proposed application about user location statistics. (a) Daily chart of user movements in the house. (b) Weekly chart of user movements in the house.

IV. Experiments and Evaluations

In this section, we describe an experiment in which the user handwrites the location and an automatic movement log experiment of the proposed application in-house to verify the performance of the proposed application and analyze the results. As shown in Fig. 5, the experimental space was 60 m^2 (3 rooms, 1 living room, 1 kitchen, and 1 toilets) and 84 m^2 (3 rooms, 1 living room, 1 kitchen, and 2 toilets). We let the user write the location manually by staying in the location for at least 1 min, and the user wrote the arrival time on the notebook after arriving at the location. We used five Bluetooth beacons (Basbea co. i3) and Apple iPhone 14 Pro Max for the proposed application operation. The Tx Power value of the i3 beacons was set to −20 dBm, and the broadcasting interval was set to 500 ms. The beacon name used "MiniBeacon," which was set at the beginning of its release.



(a)



(b)

Fig. 5. Floor plan of the two spaces for the experiment using the user's handwritten logs and the proposed application. (a) user space of 60 m^2 (b) user space of 84 m^2.

The beacons were installed on the ceiling in the center of each experimental location, and the names were set as aliases at each place in Fig. 5. First, for the performance experiment of the application with the moving average filter, we conducted a 6-hour (from 2 P.M. to 8 P.M.) user movement measurement experiment in the space shown in Fig. 5(b). Participant in the experiment handwritten records of his movements. Participant was then allowed to carry two smart devices when moving, allowing the proposed application to automatically store the movement log record. Tables II and III. show some of the user's handwritten values and the proposed application movements log data. Table II. shows that the user manually wrote the location name and time of entry at the location on the notebook. Stay is the time the user stayed in the space and is the value of calculating the time difference after moving to the current location from the previous location. Table III. shows the user movement log data of the same time stored by the proposed application. In index 917–919, the user's stay time is the same, while the user's stay time differs by 1 min in the Kitchen of 916 and the Living Room of 915. This is expected to be an error value caused by a time difference of less than 1 min when calculating up to seconds and the time required for the user to write by hand.

TABLE II. User Handwritten Record on the Notebook

Location	Time	Stay
Room 2	10. 9. 19:05	18
Room 1	10. 9. 18:57	8
Living room	10. 9. 18:22	35
Kitchen	10. 9. 17:43	39
Living room	10. 9. 16:35	68

TABLE III. User Movement Log Data of the Proposed Application

Index	Location	Start time	End time	Spend time
919	Room 2	1696845934	1696847036	18
918	Room 1	1696845419	1696845934	8
917	Living room	1696843318	1696845419	35
916	Kitchen	1696841001	1696843318	39
915	Living room	1696836925	1696841001	68

To confirm the accuracy of the proposed application after 6 h of experimentation time in home space of Fig. 5(b), we drew a graph of the handwritten records and user movement logs of the application using two smart devices, as shown in Fig. 6. In Fig. 6, in the application of the smart devices, the moving average filter value is set to 5 and 10.

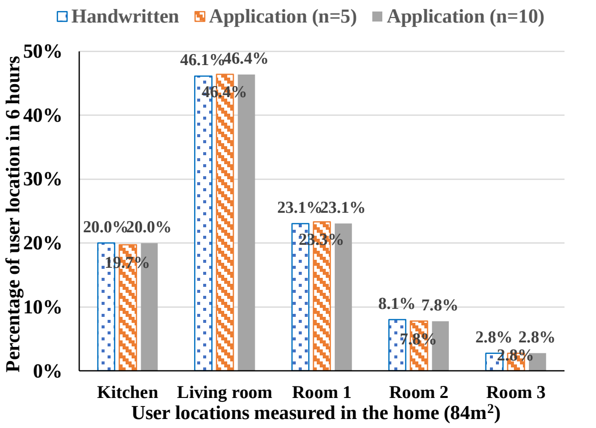
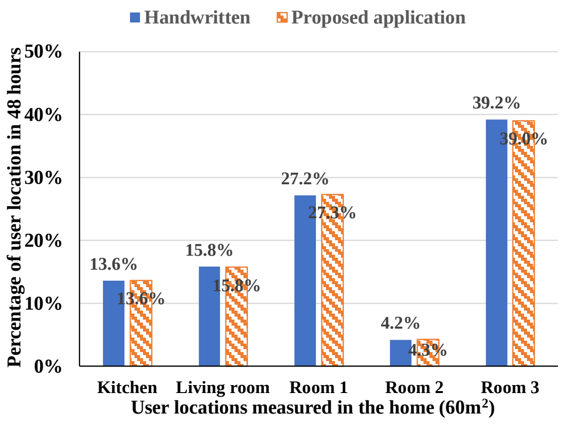


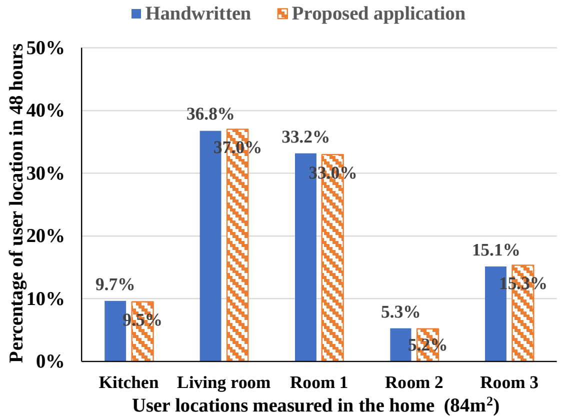
Fig. 6. A comparison graph of the results of user handwritten records and movement log data using the proposed application with moving average filter values set to 5 and 10 during 6 hours.

Participants stayed in Kitchen for 20% (72 min) as meal, tea, and snack time of the total 6 hours. He stayed 46% (166 min) in Living Room and 23% (83 min) in Room 1. When the moving average filter value is 5, the error between handwritten and proposed application values is 1.1% (0.3%, 0.3%, 0.2%, 0.3%, 0%). And when the moving average filter value is 10, the error between handwritten and proposed application values is 0.6% (0%, 0.3%, 0%, 0.3%, 0%). Thus, we found that the accuracy of the proposed application was higher when the moving average filter value was 10 than 5.

As a second experiment, the experiment period was two days and we conducted the experiment from 10:00 a.m. on the start date of the experiment to 10:00 a.m. 2 days later for a 48-hour period. At this time, the moving average filter value of the application was set to 10, and the experiment was conducted in two spaces, Fig. 5(a) and (b), respectively. To confirm the accuracy of the proposed application after 48 hours of experimentation in the two spaces, we drew two graphs of the handwritten records and user movement logs of the application, as shown in Fig. 7. In Fig. 7(a), the users of the 60 m^2 space in Fig. 5(a) had a high proportion of using rooms 1 and 3, and we could predict that the user sleeps in Room 3 and mainly works in Room 1. The user's time spent in the kitchen and living room are similar. Fig. 7(b) shows that in the 84 m^2 space in Fig. 5 (b), the other user had the highest proportion of staying in the living room, followed by Room 1. In other words, we expect this user to mainly work in the living room and that Room 1 is the user's bedroom. We expect Room 3 to be a hobby space, as the user spent an hour and a half a day in that space. And we can estimate that the user of Fig. 5(a) space spent more time in the Kitchen than the user of Fig. 5(b) space because Fig. 5(a) user cooks his own meals. On the other hand, we expect that the user of Fig. 5(b) space did not allocate much mealtime compared with the user of Fig. 5(a) space. In Fig. 7(a), the error rates between the user's handwritten data on time spent in a location and the user's movement logs generated by the application are as follows: Kitchen, 0%; Living Room, 0%; Room 1, 0.1%; Room 2, 0.1%; and Room 3, 0.2%, which are 1% in total. In Fig. 7(b), the error rates are as follows: Kitchen, 0.2%; Living Room, 0.2%; Room 1, 0.2%; Room 2, 0.1%; and Room 3, 0.2%, with an overall error rate of 0.9%. This error is estimated to be due to an error occurring within 1 min of writing the movement information and the staying time after the user's location movement, as shown in Table 2. Thus, we could confirm that the proposed method has an error rate of less than 1% compared with the handwritten record by the user in spaces Fig. 5(a) and (b).



(a)



(b)

Fig. 7. A comparison graph of the results of user handwritten records and movement log data using the proposed application during 48 hours of experiment time. (a) Results from the 60 m^2 space. (b) Results from the 84 m^2 space.

V. CONCLUSION AND FUTURE RESEARCH

In this paper, we propose an application that can store user movement logs in the house using multiple beacons and smart devices, and check daily and weekly statistics on the users' indoor locations. We present a method for non-experts to easily install beacons and designate aliases for spaces, allowing for easily recording user movement logs in-house, without the help of experts in beacon installation for indoor triangulation. To verify the performance of the proposed application, we conducted an experiment in which a user noted their location and movement time on the notebook by hand and the application automatically stored the user movement log. As a result, we confirmed that the proposed application has an error rate of less than 1% and excellent performance. Thus, the user indoor movement log application using Bluetooth beacons proposed in this paper is a useful application that even nonprofessionals can easily install and use beacons. It is an excellent application that allows users to check their daily and weekly statistics to see where they spent a lot of time. In addition, the proposed method will be an excellent technology that can be applied and used immediately in a small office with 10 or fewer employees.

As for future research, the application proposed in this paper is limited to indoor location tracking. However, people spend time not only inside the house but also outside the house, moving to many destinations using various means of transportation. In other words, in addition to analyzing movement and space usage time from the user's home, the usage time in transportation when using public transportation and private vehicles must be necessary to store and analyze. Therefore, we will extend the capabilities of the application proposed in this paper and study additional data collection techniques for user movement data collection outside the house, movement logs in the office, and time spent in a space. In addition to using beacon signals, we will conduct further research and experiments using mixed signals such as access points and high-frequency signals that can be received on subways and buses.

Conflict of Interest

The author declares no conflict of interest.

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