Indoor Location Estimation Considering Movable Obstruction by Using Multi-Hop Beacon Information

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We can use a lot of services using positioning system. Accordingly, there is a problem about improving indoor positioning accuracy. In this research, by using the mobile terminal (smartphone and tablet) as a kind of beacon, we propose a method that can estimate positions with higher precision in a place with many people than previous ones. We attempt to improve the positioning accuracy by calculating distances between each device with RSSI considering movable obstructions. We experimented in a real environment and applied a proposed method to an environment where we set three BLE beacons and three humans who have mobile devices. As a result, compared with previous methods, the positioning accuracy improved, which showed the superiority of this method.

Key words: positioning system, RSSI, positioning accuracy

1. Introduction

In recent years, the number of people who use mobile devices such as smartphones, tablets, and wearable devices has been increasing, and there are many services that can be used on the mobile devices. In addition, location estimation technology can be used in them. Currently, Global Positioning System (GPS) services are the most common way for users to obtain their own location information. However, since GPS estimates position by receiving and calculating signals from multiple satellites, the accuracy of position estimation may be compromised if there are obstacles such as buildings or roofs that block the signals from the satellites. The problem is that such services cannot be used properly in places such as smart homes, shopping malls, and underground. Accordingly, a lot of research about indoor location estimation has been done[1,2]. Indoor location estimation methods include Wi-Fi, Bluetooth Low Energy (BLE), and sensors mounted on mobile devices such as smartphones. These indoor location estimation methods are being developed for practical use, and are expected to be used in train stations, airports, and commercial facilities. However, they suffer from various problems such as poor location estimation accuracy due to the influence of obstructions and distance attenuation of radio waves[3].

We define location estimation and location estimation accuracy in this study as follows.

- Location estimation - To compute the location of a user's mobile device using a location estimation method.
- Location estimation accuracy - It means the error between the result of location estimation and the actual location of the user's mobile device.

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2. Related Methods

2.1 *Location estimation method using BLE*

BLE is a part of the Bluetooth 4.0 standard, which enables low power consumption communication. BLE does not require prior pairing and is used for location estimation. If a mobile terminal such as a smart phone or a tablet that supports BLE can receive radio waves from three or more BLE beacons that have been set up in advance, it is possible to estimate the location[4)]. However, the BLE signal uses the 2.4 GHz communication band, which is easily affected by reflection and shielding of radio waves, and the human body, which contains a lot of water, may affect the strength of the received radio wave[5,6)]. One solution to this problem is to increase the number of beacons, to make the distance to the beacons closer, and to increase the number of signals that are not blocked by obstacles. However, this method is not reasonable because it is costly.

2.1.1 *Received Signal Strength Indicator (RSSI)*

Received Signal Strength Indicator (RSSI) is one of the most commonly used characteristics for indoor location estimation[7)]. It is a measure of the signal strength of the received signal sent from an access point to a client device or vice versa in wireless communications such as wireless LAN and Bluetooth. Since the received signal strength attenuates in inverse proportion to the square of the distance, it is possible to estimate the distance between the sending and receiving terminals by measuring the RSSI value. To estimate the distance from the RSSI value, Eq. (2.1) is generally used.

$$RSSI = TxPower - 10 x N x log(d) \quad (2.1)$$

RSSI is the radio strength at a distance of d[m] from the source [dBm], TxPower is the radio strength at a distance of 1m from the source [dBm], and N is the radio loss index. The value of N should be set as follows.

N=2.0 : Ideal space with no obstacles

N<2.0 : A space where radio waves propagate while being reflected

N>2.0 : A space that propagates while being absorbed and attenuated by obstacles

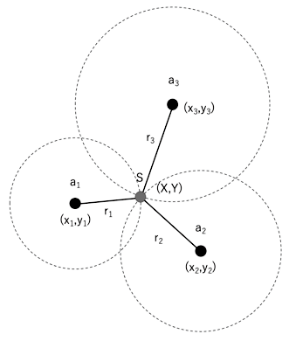

Fig. 1. Position estimation by trilateration.

2.1.2 *Trilateration*

Trilateration is a location estimation technique that can be used when radio signals from three or more terminals can be received. The location is estimated from the distance between each of the transmitting and receiving devices and the location information of the transmitting terminal. Three transmitting devices are continuously transmitting signals. The receiver node can record the RSSI of all the signals it receives, and by converting the RSSI into distance, it can estimate the distance between the sending and receiving terminals. The RSSI can be converted to distance by using the path loss model. When the three transmitting terminals are a1, a2, and a3, and their coordinates are (x1, y1), (x2, y2), and (x3, y3), respectively, and the distance between the transmitting and receiving terminals is r1, r2, and r3, the position s (X, Y) of the receiving terminal can be estimated by solving Eqs. (2.2)-(2.4)[8)].

$$r1^2 = (X - x1)^2 + (Y - y1)^2 \quad (2.2)$$

$$r2^2 = (X - x2)^2 + (Y - y2)^2 \quad (2.3)$$

$$r3^2 = (X - x3)^2 + (Y - y3)^2 \quad (2.4)$$

2.2 *Multi-hop location estimation method for beacon information*

As a location estimation method that does not limit the location of use, there is a method that uses radio waves from multiple sources, not only GPS satellites and beacons, but also mobile terminals such as smartphones and tablets in the surrounding area[9)]. In this system, a mobile terminal owned by a person in the vicinity becomes a radio wave transmitter or receiver in a specific environment. When estimating its own location, a mobile terminal uses not only beacons placed in advance, but also signals from other mobile terminals that have already estimated its location. In addition, the mobile terminal that is the source of the radio wave can both transmit and receive the radio wave. Therefore, it can estimate its own position even when it is the source of the signal. In this way, without increasing the number of radio sources such as GPS satellites and beacons, we have solved the problem of poor location estimation accuracy when the distance to the beacon is far. This method takes into account the ambiguity of radio waves, such as the fact that it becomes difficult to receive an accurate radio wave strength when the distance from the source is far, and the fact that radio waves are affected by people and walls. However, in environments such as shopping malls and underground malls where there are multiple people in close proximity, the system does not fully take into account the effects of the human body.

2.3 *A method using BLE considering movable obstruction*

Since Bluetooth uses the 2.4 GHz band, it has characteristics such as reflection, shielding, and analysis. In particular, because it is easily absorbed by water, it is greatly affected by people who contain a lot of water. In other words, when estimating the location of a retail store or a shopping mall, there may be a large number of people, and the influence of people on the radio wave becomes a problem. Therefore, Hoshi et al. [10] have proposed a location estimation method that takes into account human traffic, which is a dynamic barrier that absorbs radio waves, as a challenge for indoor location estimation using wireless signals, especially BLE. By using a camera installed on the ceiling, the positions of multiple dynamic shields are acquired. The error is reduced by selecting the best transmitter from among several BLE beacons installed in advance. We have succeeded in improving the position accuracy in environments where there are multiple people present, but this method requires a special camera to be installed beforehand.

3. Proposed Method

3.1 *Overview*

We propose a method to improve the accuracy of location estimation by taking into account the effect of movable obstructions (human bodies) in an indoor environment where there are multiple people around. For location estimation, we use pre-installed BLE beacons and signal strength from other mobile terminals. When each mobile terminal estimates its own position, it also transmits signals, so that it can play the role of a beacon. By using mobile terminals as beacons, we can improve the estimation accuracy without increasing the number of installed beacons. In addition, since there must be more than one person in the area, it is assumed that the radio wave strength from each terminal may be affected by the human body, resulting in a decrease in the received radio wave strength. To solve this problem, we created two path loss models in advance, one with and one without the influence of the human body, which are used to calculate the distance from the RSSI. Then, the distance is calculated by using the two different path loss models. In this way, we can reduce the error in the calculated distance when the radio wave is affected by the human body and improve the accuracy of the terminal location estimation.

3.2 *prerequisite*

- Every person owns a mobile device.
- All people hold a mobile device in their hands and hold it in the direction they are facing.
- Each mobile terminal owns the location information of each installed beacon.
- Each mobile terminal shares with each other the direction the terminal is facing and its estimated location.

3.3 *considering movable obstruction*

Determine if the received radio wave is affected by the human body. If the received radio wave is affected by the human body, the distance is calculated using the path loss model when affected by the human body. This is called the consideration of movable obstruction (human body).

Next, we will explain the conditions for determining whether a human body has been affected. First of all, the conditions for discriminating radio waves from beacons are that the beacon exists in the opposite direction of the direction that the person holding the receiving terminal is facing, and that the person holding another terminal exists in the rectangle formed by the diagonal line connecting the beacon and the receiving terminal.

The condition for discrimination about radio waves from other mobile terminals is that the person who owns the transmitting terminal and the receiving terminal are not facing each other.

3.4 *location estimation algorithm*

In this study, we use the distance between the sending and receiving terminals estimated from the RSSI and the location information of the known sending terminal to estimate the location using the algorithm described below.

We assume that the sending terminals (B1, B2, B3) and the coordinates of each terminal are B1 (X1, Y1), B2 (X2, Y2), and B3 (X3, Y3). We use our previously created path loss model to estimate the distance between the sending and receiving terminals by converting the RSSI of each sending terminal into distance. We set the estimated distances between B1, B2, and B3 and the receiving terminal as R1, R2, and R3, respectively, draw circles with radii of R1, R2, and R3 centered on B1, B2, and B3, and set the center of gravity of the triangle formed by the midpoints of each two circles as the estimated position of the receiving device. The center of the triangle formed by the midpoints of the two circles is the estimated position of the receiving device. The point with the smallest distance from the arc of the two circles is the midpoint of the two circles.

The midpoint of two circles can be divided into the cases where the circles are separated, inside one of the circles, circumscribed, intersected by two points, and inscribed. When the circles are far apart or inside one of the circles, the midpoint is the red point shown in Fig. 2 and 3.

If the two circles are circumscribed (Fig. 4) or inscribed (Fig. 5), the point of contact is the midpoint of the two circles; if the two circles intersect (Fig. 6), the intersection point is the midpoint, and the point with the smallest combination of distances to the midpoints of the other two circles is used for position estimation.

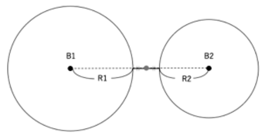

Fig. 2. Two circles are separated.

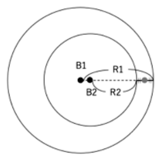

Fig. 3. Inside one of the circles.

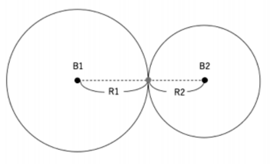

Fig. 4. Two circles are circumscribed.

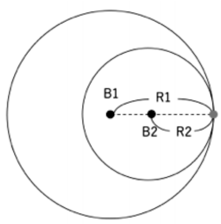

Fig. 5. Two circles are inscribed.

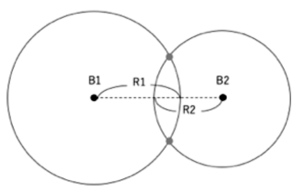

Fig. 6. Two circles intersect.

3.5 *Location estimation flow*

(1) Each mobile device receives a signal from the installed beacon.

(2) Each mobile device calculates the distance from the RSSI value of the received signal and estimates its own position.

(3) Each mobile device recalculates the distance based on the orientation of its own terminal and the estimated location of each device to determine if the received signal was affected by movable obstructions.

(4) Each device uses the recalculated distance to estimate its own position again. Then, each one will emit its own signal.

(5) Each mobile device selects the three strongest signals from the RSSI values of the received beacons and signals from other terminals.

(6) From the estimated distance and the location information of each terminal, the device estimates the location.

4. Experimental Setup

4.1 *Environment*

Since the purpose of the experiment was to consider the effect of the human body on the radio waves, we conducted the experiment in a room of about 6 m x 9.5 m with few obstacles other than people. The beacon was placed on the vertex of a right triangle, and the distance d between AB and BC was set to 3 m. The beacon was placed on a desk so that the height of the beacon was close to the devices held by a person. For the RSSI used, 100 measurements were taken from each transmitting terminal, and the maximum value was used.

In order to investigate how well the proposed method works when the human body is affected by the radio waves from the beacon and other mobile devices, we placed three people holding mobile devices in such a way that each person is affected by the radio waves from the beacon and other devices. We conducted measurements at three different locations, each with three

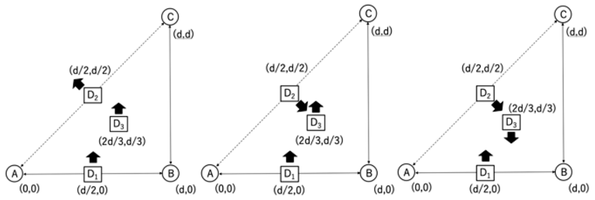

Fig. 7. A Layout of the experiment.

different placement methods, so that the number and type of radio waves affected by each person varied. Figure 7 shows the actual layout of the experiment, where A, B, and C are beacons, D1~D3 are people holding mobile terminals, and the arrows indicate the direction of the people.

4.2 *Hardware Components*

In this study, we used the Apple iPod touch 7th generation for all three mobile terminals and three installed beacons. In order to minimize the differences in signal strength between the devices, we used the same type of device for our experiments.

4.3 *Path Loss Model*

Before conducting the experiment, we created two different path loss models, one with and one without the influence of the human body. We placed one transmitter and one receiver and recorded the RSSI values at different distances. To determine how the RSSI values decreased with the distance between the transmitter and receiver, we took measurements at a total of 14 points at distances ranging from 0.5 to 5 m. Each point was measured five times every 0.1 m between 0.5 and 0.9 m, and nine times every 0.5 m between 1 and 5 m. After all the points were measured, we used Scipy's fitting function to create a model based on the equation.

Since the path loss model uses the radio wave strength of the devices at the time of radio wave transmission, it is necessary to prepare a path loss model for each device if there is a difference among devices in the source of the signal to be used. In this experiment, we

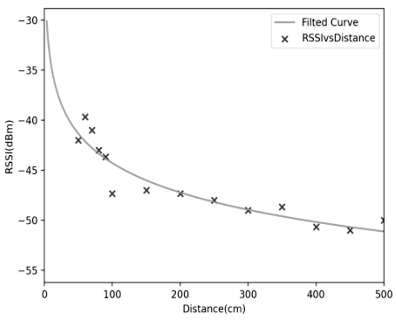

Fig. 8. The model without an effect by human body.

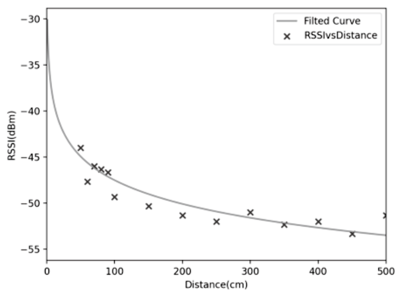

Fig. 9. The model with an effect by human body.

use the same type of terminals for both mobile terminals and installed beacons, so there are only two path loss models: one for the case where the mobile device is affected by the human body and one for the case where the mobile device is not affected by the human body.

Figure 8 and Figure 9 show the curve models of the path loss for the case without human influence and the case with human influence.

4.4 *Evaluation Methods*

The differences between the proposed method and the existing methods are shown in Table 1. In the existing method 1, only the signal from the installed beacon is used for location estimation. In the existing method 2, all signals are received by using the installed beacon, the location information of each mobile device estimated by the existing method 1, and signals from other mobile devices. Then, the location is estimated by using three signals in the order of RSSI strength. The proposed method is described in Chapter 3.

Table 1. The difference of methods.

Existing method 1	Using only beacons
Existing method 2	Using beacons and mobile devices
Proposed method	Using beacons and mobile devices and considering movable obstruction
Proposed method (first stage)	Using beacons and considering movable obstruction

We use the estimated position in (4) of the location estimation flow described in Chapter 3, Section 5 as the proposed method (first stage) and compare it with the existing method 1. We define the location error as the average of the difference between the location estimated by each method and the distance of the actual location of the mobile device, and we also compare its standard deviation.

4.5 *Results*

The results of the location estimation are shown in Fig. 10. The mean and standard deviation of the errors in Fig. 10. are shown in Table 2, indicating that the proposed method improves the accuracy of location estimation compared to the existing methods. The results for each mobile device are shown in Fig. 11 and Fig. 12. The accuracy of the proposed method is higher than that of the existing method for all the mobile devices.

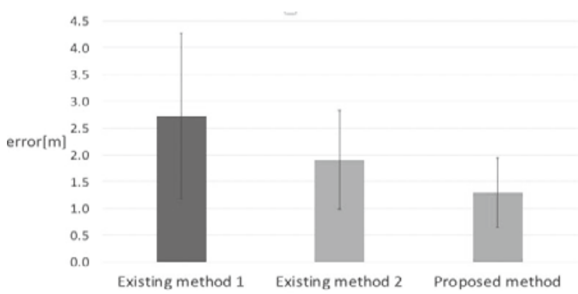

Fig. 10. The experimental result.

Table 2. The parameters of Fig. 10.

	Average error	standard deviation
Existing method 1	2.7 m	1.5 m
Existing method 1	1.9 m	0.9 m
Proposed methods	1.3 m	0.7 m

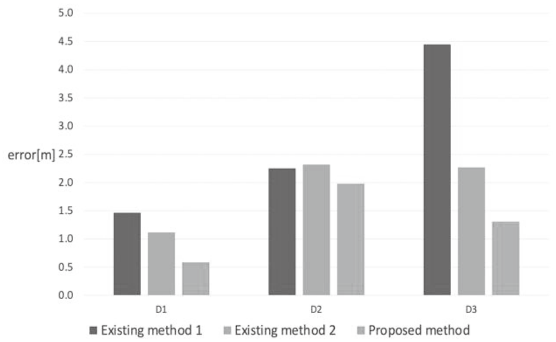

Fig. 11. Location estimation error for each mobile device.

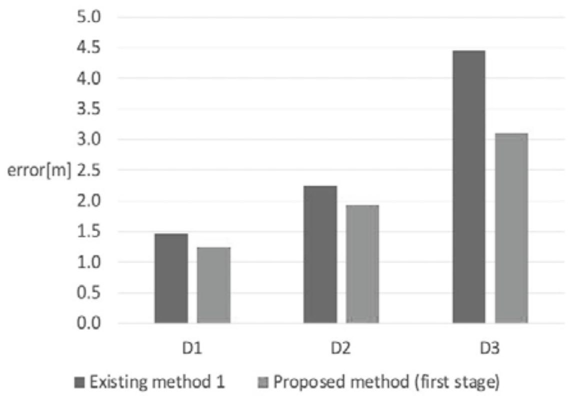

Fig. 12. Location estimation error for each mobile device.

5. Discussion

Figure 10 shows that the location estimation accuracy of the proposed method is better than that of the existing methods 1 and 2. In addition, as shown in Fig. 12, even in the case of only radio wave information from beacons, the error of the proposed method is smaller than that of the existing methods, because the proposed method takes into account the movable obstructions. These results show that the proposed method is effective in environments that are easily affected by movable obstructions (human bodies).

The reason why the error of D1 is smaller than that of D2 is that the distance between the left and right beacons of D1 is shorter than that of D2, so the error of the estimated distance from the beacons is smaller.

The position estimation error of the existing method 1 at D3 was larger than the other methods. This is because the signals from the beacons used for location estimation were often affected by people, such as people in front of and behind the beacons, only one or two beacons in front of itself, and signals from other beacons were blocked by its own body at the D3 location. In the existing method 2, we select the signal with strong RSSI from beacons and other mobile devices, and the error is reduced by increasing the number of uninfluenced signals used for location estimation. The error of the proposed method is smaller than that of the existing method 2 because the location information of other mobile devices, which is required when using the radio waves of other mobile devices, is estimated by considering the human body.

In D2, the accuracy of location estimation was worse for the existing method 2 than for the existing method 1. The proposed method also showed a smaller decrease in error than the other mobile devices. As shown in Fig. 12, in the case of beacons only, the error is reduced by considering the movable obstructions. Nevertheless, the accuracy of the beacon-only method is poor because it uses the radio wave of the mobile device, which is far different from the actual location, for location estimation. In this study, when using beacon and mobile device signals, we selected three signals with high signal strength from all received signals. The use of signals from other mobile devices may reduce the error, but if the estimated positions of the mobile devices used are far off, the error may accumulate.

In this study, we developed a path loss model with and without a human body to investigate whether the accuracy of location estimation can be improved by using different path loss models to take into account the effect of the human body as a movable obstruction. However, the magnitude of the effect of the human body varies depending on the arm holding the mobile device and the body size of the person. In the environment of this study, the accuracy was improved by the created model, but in other environments, the error of the two models may become larger. In order to cope with all kinds of situations, it is necessary to create multiple models depending on the degree of influence of the human body and to devise a method of discriminating the presence or absence of a human body.

6. Conclusion

In recent years, there has been an increase in the use of mobile devices such as smartphones, tablets, and wearable devices. GPS is commonly used for location estimation, but its usage is limited. There are many services that can be used with GPS, and many of them use location information technology. One of them is a location estimation method using BLE. In order to improve the accuracy, it is necessary to prepare a large number of BLE beacons for installation, and there is a problem that the accuracy becomes poor in an environment where there are multiple people.

In this study, we proposed a new location estimation method to improve the accuracy of location estimation in an environment where there are multiple people without increasing the number of beacons. The path loss model used to calculate the distance from each beacon was created in advance for the case with and without the influence of people. The distance between the devices was calculated using the two path loss models by using the surrounding mobile devices as beacons and by determining whether the received radio waves were affected by people or not. The distance between the devices was calculated using two different path loss models. The location was estimated taking into account the movable obstructions.

In this experiment, we applied the proposed method to a space with three installed beacons and three people with mobile devices and compared the accuracy of location predictions with those of existing methods. As a result, we confirmed that both the accuracy of location estimation at each device and the average of them were better than the existing method.

Since the experiment was conducted in an environment that is easily affected by people, who are movable obstructions, the existing method 1 had a large error. The existing method 2 could reduce the error by using other mobile devices, but it was not enough. The proposed method can further improve the accuracy by estimating the location considering the movable obstructions. However, when the error in the location information of the mobile device used for location estimation was large, the error was sometimes almost the same, therefore, there is a problem in the selection method of the radio wave used for location estimation.

We showed that the proposed method can improve the accuracy of location estimation in indoor environments with multiple people without increasing the number of beacons.

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