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Reducing the Effect of a Human Body for Position Estimation using iBeacon

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***Abstract*—In recent years, indoor and outdoor position information has been used in various services. The Global Positioning System (GPS) is most used to know position information. However, GPS cannot estimate the position indoors, where the signal from the satellite is difficult to receive. Thus, using the received signal strength indicator of iBeacon has been proposed. Beacon's signals are in the 2.4GHz band, and the signal in the 2.4 GHz incurs the effect of a human body. Beacon's signal passing through a human body is greatly attenuated. This causes errors in the estimation of the position. In this study, we reduce the error of the estimated position caused by a human body. the effect of the human body is reduced by using the displacement of the estimated distance to estimate the position. In addition, the accumulated error in position estimation using the displacement of the estimated distance is correct by detecting the passage of the receiver.**

***Index Terms*—iBeacon, position, estimation, effect of a human body**

I. Introduction

In recent years, indoor and outdoor position information has been used in various services. Outdoor position information is used for car navigation systems that estimate the position of a car and show the driving route to a destination. In smartphone games, the estimated position of a smartphone is used to generate an event when it approaches a specific position. Indoor position information is used in services such as the article position management system [1] and a tracking system [2]. In [2], the position of people in a welfare facility is used to monitor their access to dangerous areas.

Many outdoor position-based services use the Global Positioning System (GPS), which uses signal transmitted from satellites to estimate a position. Therefore, it enables to estimate a position where it is possible to receive the signal transmitted from satellites. However, GPS cannot estimate the position indoors, where signals from satellites are difficult to receive.

Thus, various indoor position estimation methods, which use WiFi access points [3] and magnetic sensors [4], and so on, have been proposed. One of them uses Received Signal Strength Indicator (RSSI) of iBeacon. iBeacon uses the BLE (Bluetooth Low Energy) [5] which is a Bluetooth standard that consumes low power. iBeacons are small, low-cost and low-powered, thus, long hours of operation are possible with low power consumption. However, there is a problem with large estimation errors caused by various environmental conditions. Beacon's signals are in the 2.4 GHz band, and the signal in the 2.4 GHz incurs the effect of a human body. Beacon's signal passing through a human body is greatly attenuated. This causes errors in the estimation of a position. In this study, we reduce the error of a estimated position caused by the effect of a human body.

II. Related Research

Fingerprinting method and Centroid method have been proposed for position estimation using RSSI of a beacon [6]. In the Fingerprinting method, the location estimation area is divided into multiple blocks, and RSSI of the beacon observed in each block is recorded in advance. By comparing the recorded RSSI and a measured RSSI, it estimates a block the beacon exists. In the Centroid method, a distance between a beacon and a receiver is calculated from RSSI of the beacon, and the center of gravity is estimated as the position the beacon exists.

There is two way of the position estimation based on RSSI: one is to estimate the position of a beacon based on RSSI which multiple receivers received [7] [8], and the other is to

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estimate the position of a receiver based on the RSSI sent from multiple beacons [9]–[11].

A. Estimate the Position of a Beacon

Urano et al. [7] compare the accuracy of position estimation between a method based on RSSI corrected by Denoising Autoencoder and End-to-end neural network method. The method using Denoising Autoencoder uses a three-point positioning algorithm to estimate a position based on RSSI corrected by the Denoising Autoencoder. The method using End-to-end neural network estimates the position based on RSSI in chronological order. However, the effects of a human body are not considered.

Iwasaki et al. [8] propose to reduce the effects of a human body. This study makes use of two beacons in front and behind a body. The effect of a human body is reduced by calculating the midpoint of the estimated position of two beacons. However, this method requires a person has to possess two beacons.

B. Estimate the Position of a Receiver

Sakai et al. [9] extract four large RSSI from signals received from multiple beacons and estimate a position by three-point positioning from the extracted four RSSI. However, the effects of a human body are not considered.

Hoshi et al. [10] propose a method using cameras to support the estimation of beacons' position. Cameras are used to detect obstructions such as people and objects between a beacon and a receiver. The position is estimated by three-point positioning using only the beacons which are not affected by obstructions. However, this method requires cameras in addition to beacons. Thus, it is expensive to implement, and afraid of privacy violation.

Furutachi et al. [11] propose a method to use the displacement from a previous estimated position. A vector space model is created based on the displacement of the previous RSSI and current RSSI. The direction of movement is determined from the vector space model created. The vector space model is not used to calculate a displacement, but it is calculated with an acceleration sensor. A position is estimated by the displacement from a previous estimated position to the direction of movement. In this study, as well as Furutachi et al., we estimate a position using a displacement from the previous estimated position. Furutachi et al. needs an acceleration sensor to estimate the displacement of movement. However, our study does not needs an acceleration sensor.

III. Position Estimation using Centroid Method

We have developed an indoor tracking system of a person who has a beacon. In our system, receivers are installed in a building, and a person has a beacon. The beacon periodically transmits a signal. A receiver installed in the building receivers the signal from the beacon and transmits it to a server. The server estimates a position based on the signals transmitted from multiple receivers. In this system, RaspberryPi 3 model B [12] is used as a receiver and MyBeacon pendant type [13] is used as a beacon.

A. Centroid Method

Our system uses the Centroid method for position estimation. In the Centroid method, the center of gravity calculated is used as the estimated position. A distance between a beacon and a receiver is used as a weight. The distance between a beacon and a receiver is calculated using the Friis Transmission Equation [14]. Let RSSI at a point $1m$ away from a beacon be $p_1[\mathrm{mW}]$ and RSSI at distance $r[\mathrm{m}]$ be $p_r[\mathrm{mW}]$, then the distance between a beacon and a receiver can be expressed in (1) from the Friis Transmission Equation.

$$p_r = \frac{p_1}{r^2}[\mathrm{mW}] \tag{1}$$

In general, the RSSI of a beacon is measured in dBm. Then, when $p_1[\mathrm{mW}]$ is converted to $P_1[\mathrm{dBm}]$ and $p_r[\mathrm{mW}]$ to $P_r[\mathrm{dBm}]$, P_1 and P_r are expressed in (2) and (3), respectively.

$$P_1 = 10\log_{10} p_1[\mathrm{dBm}] \tag{2}$$

$$P_r = 10\log_{10} p_r[\mathrm{dBm}] \tag{3}$$

Applying (2) and (3) to (1) gives (4).

$$P_r = P_1 - 20\log_{10} r[\mathrm{dBm}] \tag{4}$$

In (4), a distance r can be expressed in (5).

$$r = 10^{(P_1 - P_r)/20}[\mathrm{m}] \tag{5}$$

The distance r calculated in (5) is considered as the weight. A position is estimated to be calculated by the center of gravity $T(x_t, y_t)$ from (6). n is the number of receivers installed, (x_i, y_i) is the position of coordinates of the i-th receiver, r_i is the distance between the i-th receiver and a beacon.

$$T(x_t, y_t) = \left(\frac{\sum_{i=1}^{n} \frac{x_i}{r_i}}{\sum_{i=1}^{n} \frac{1}{r_i}}, \frac{\sum_{i=1}^{n} \frac{y_i}{r_i}}{\sum_{i=1}^{n} \frac{1}{r_i}} \right) \tag{6}$$

B. Corresponding to Unstable Signals

The signals emitted from a beacon are affected by disturbance with various environmental conditions. Therefore, even though the distance between a beacon and a receiver is constant, RSSI received are unstable. Unstable RSSI causes an error in a estimated position.

The signals emitted from a beacon are reflected off walls and floors. Since the reflection of signals extend the path from a beacon to a receiver, RSSI received is attenuated from the actual strength of RSSI at an actual distance. In addition, a beacon uses the 2.4GHz band and interferes with WiFi signals. The signals interfere with each other, which amplifies or attenuates its strength. In some cases, the interference cancels out a signal, thus, receivers may not receive a signal.

Therefore, the improvements have been done to reduce the error caused by the unstable of beacons signals [15]. Those improvements reduced the mean error about 31%, from 2.13 m to 1.46 m. The improvements we have done are described below.

1) Using the Average of RSSI: If RSSI of a detected beacon is directly used for the calculation of position estimation, the position estimation results are not stable due to disturbances. RSSI changes even though a beacon is stationary at a certain position. However, when we examine the distribution of RSSI, many of them are near the actual position. Therefore, we use the average of RSSI collected at a certain time for position estimation.

2) Outlier Removal: There are outliers that is significantly different from the RSSI average. The outliers are considered to be caused by the reception of signals reflected from walls and floor. If the RSSI average is calculated with outliers, the average of RSSI deviates from the actual value. Therefore, we collect signals for a certain period, and remove signals that are more than ± 2 dBm away from the median of RSSI before the RSSI average is calculated.

3) Exponential Smoothing: The Exponential Smoothing adjust a current RSSI based on previous estimated RSSI and current measured RSSI. According to the Exponential Smoothing Method, current RSSI $S_{r,t}$ estimated by (7). Let $P_{r,t}$ is a current measured RSSI, $S_{r,t-1}$ is previous estimated RSSI, and α is a smoothing constant.

$$S_{r,t} = \alpha P_{r,t} + (1-\alpha) S_{r,t-1} \tag{7}$$

As α approaches 0, previous estimated RSSI is given more weight; as it approaches 1, a current measured RSSI are given more weight. We use 0.6 as α, which is the smallest mean error in our experiments.

4) Using of Received Signals Count: The number of signals a receiver received differs by a distance between a beacon and a receiver. Therefore, we give more weight based on the number of signals a receiver receives. A weight ω_i is represented in (8), where c_{ri} is the number of signals a receiver i receives from a beacon in a certain period, r_i is the distance between a receiver i and a beacon, and c_a is the number of signals all receivers receive from a beacon in a certain period. In this case, the center of gravity $T(x_t, y_t)$ is expressed in (9).

$$\omega_i = r_i \frac{c_{ri}}{c_a} \tag{8}$$

$$T(x_t, y_t) = \left(\frac{\sum_{i=1}^{n} \frac{x_i}{\omega_i}}{\sum_{i=1}^{n} \frac{1}{\omega_i}}, \frac{\sum_{i=1}^{n} \frac{y_i}{\omega_i}}{\sum_{i=1}^{n} \frac{1}{\omega_i}} \right) \tag{9}$$

IV. The Effect of a Human Body

In Section III-B has reduced the error caused by unstable signals. However, the error affected by a human body has not been considered. Therefore, we confirmed the error affected by a human body.

A. Estimated Positions Under the Effect of a Human Body

We examine the difference of estimated positions by the effect of a human body when the Centroid method is used for position estimation. Figure 1 shows the results of position estimations by the Centroid method. In this experiment, two receivers were installed at 0 m and 10 m, and a person who has a beacon at his/her chest stood at the center of two receivers (at 5m). The person changes his/her direction every 30 seconds so that the person faced the receiver at 0 m and the receiver at 10 m alternately. The beacon's output signal intensity was set to -20dBm, RSSI at the distance of 1 m was set to -78dBm, and the number of transmissions per second was set to 10.

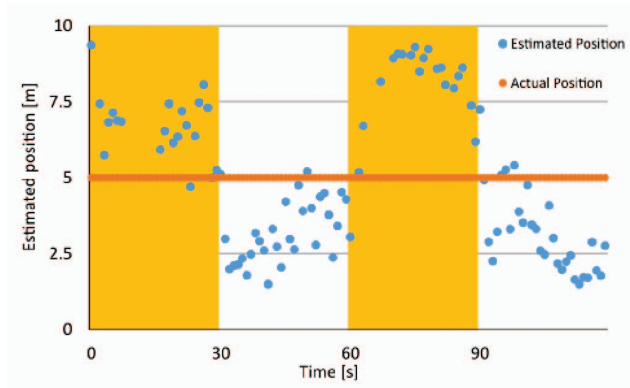

Fig. 1. Results of Position Estimation Using the Centroid Method

As shown in Figure 1, estimation positions vary greatly depending on the direction of a person, even though his/her is at 5m. This is because the signal affected by a human body was attenuated, thus, the signal received by a receiver behind the beacon is attenuated by the effect of a human body. A position is then estimated ahead of the actual position since the person has a beacon at his/her chest.

B. Difference Between Estimated and Actual Distance

In Section IV-A, we confirmed that the error is caused by the attenuation of signal affected by the effect of a human body. In the Centroid method, the distance between a beacon and a receiver is calculated by (5) based on RSSI. The distance affected by a human body is calculated farther than the actual distance. This is the cause of the error. Therefore, we examine how a distance is estimated depending on the effect of a human body when a distance between a beacon and a receiver changes.

In this examination, we install one receiver and measured RSSI at each position between 1 and 9 m. A person has a beacon at his/her chest. The estimated distances are not affected by a human body when the person is facing to the receiver, and the estimated distances are affected by a human body when the person is facing the opposite side. The average results of 90 seconds $\times$ 3 times experiments are shown in Figure 2.

Figure 2 shows the estimated distance when a human body affects and does not affect. The estimated distances calculated from signals affected by a human body are farther than those calculated from signals not affected by a human body. The difference is about 3.5 m.

Here, we focus on the displacement of the distance from the receiver, then, the difference is small. We calculated the

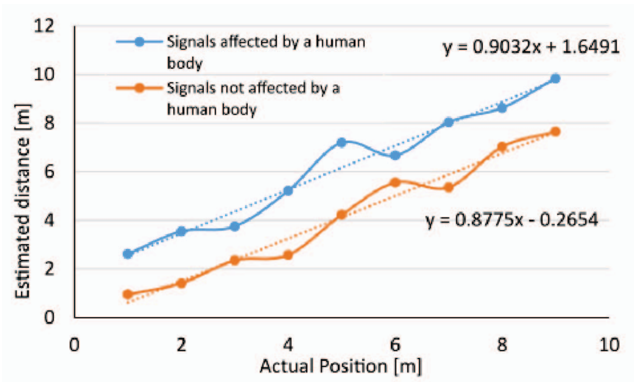

Fig. 2. Difference of estimated distances

estimated distance displacement for a 1-meter change in each distance. The average of the signal affected by a human body was about 1.0 m, while the average of the signal unaffected by a human body was 0.89 m. The difference between them was 0.11 m. This indicates that the estimated distance displacement is small a human body to be affected.

V. Reducing the Effect of a Human Body

The experimental results in Section IV show that the displacements of estimated distance are less affected by a human body. Therefore, we use the displacement of an estimated distance to reduce the error affected by a human body. The position is estimated by using both the displacement of an estimated distance and the position estimation by the conventional Centroid method.

This method consists of two parts: Movement Direction Estimation and Movement Displacement Estimation. In Movement Direction Estimation, we use the current estimated position and the last three estimated positions obtained by the Centroid method. In Movement Displacement Estimation, the displacement of movement from a previous estimated position P_{t-1} is estimated[1]. The current estimated position P_t is estimated to be the position, which moved the distance obtained by Movement Displacement Estimation from the previous estimated position P_{t-1}, in the direction estimated by the Movement Direction Estimation. The flow of this method is shown in Figure 3.

A. Movement Direction Estimation

The movement direction is estimated using the estimated positions of the last three times from $t-3$ to $t-1$ and the current time t obtained by the Centroid method. The approximate line is calculated from the three previous and current estimated positions. The movement direction is determined using the slope of this approximate line. Note that the four positions used here are the positions estimated by the conventional Centroid method. Therefore, the estimated position used here is affected by a human body. However, it does not affect the slope of the approximate line because all four estimated positions are affected by a human body. Therefore, it is not necessary to take the effect of a human body into consideration when estimating the movement direction.

The approximate line is obtained with the estimated position as the y-axis and the time series as the x-axis. Let $Cov(X,Y)$ is the covariance, and σ_X^2 and μ_X are the standard deviation and the mean of x, then the slope of the approximate line A is expressed by (10).

$$A = \frac{Cov(X,Y)}{\sigma_X^2} \tag{10}$$

In addition, let μ_Y is the mean of y, the intercept B is given by (11).

$$B = \mu_Y - A\mu_X \tag{11}$$

The approximate line from (10) and (11) is given by (12).

$$y = Ax + B \tag{12}$$

When the receiver is installed in a straight line, the movement can direction is estimated by the positive or negative values of the slope A of this approximate line.

B. Movement Displacement Estimation

In Movement Displacement Estimation, a movement displacement from the last estimated position P_{t-1} is calculated from RSSI. The estimated displacement between a beacon and a receiver is obtained from (5). The difference (displacement) between estimated distances at time $t-1$ and time t is calculated for each receivers. Let the estimated distance at time t be d_t and the estimated distance at time $t-1$ be d_{t-1}. The displacement Δd is given in (13).

$$\Delta d = d_t - d_{t-1} \tag{13}$$

Here, Δd may be in a different direction from the direction obtained by the estimation of Movement Direction Estimation in Section V-A. This displacement is not accurate when we suppose that the direction estimated by Movement Direction Estimation is correct. Therefore, we extract only the displacements which have same direction with the direction estimated by Movement Direction Estimation, from the displacements obtained for each receiver.

Then, weights are assigned to each displacements extracted in each receivers. The weights is the number of signals each receiver receives between time $t-1$ and time t. Let the number of displacements extracted is m, and the number of signals the receiver i receives between time $t-1$ and time t is s_i, then the estimated move displacement D is expressed by (14).

$$D = \frac{\sum_{i=1}^{m} \Delta d_i s_i}{\sum_{i=1}^{m} s_i} \tag{14}$$

In this case, the estimated position P_t is represented by (15).

$$P_t = P_{t-1} + D \tag{15}$$

[1]It is possible to calculate the movement direction by a positive and negative numbers of the displacement in the Movement Displacement Estimation. However, in our experiments, its accuracy has been low.

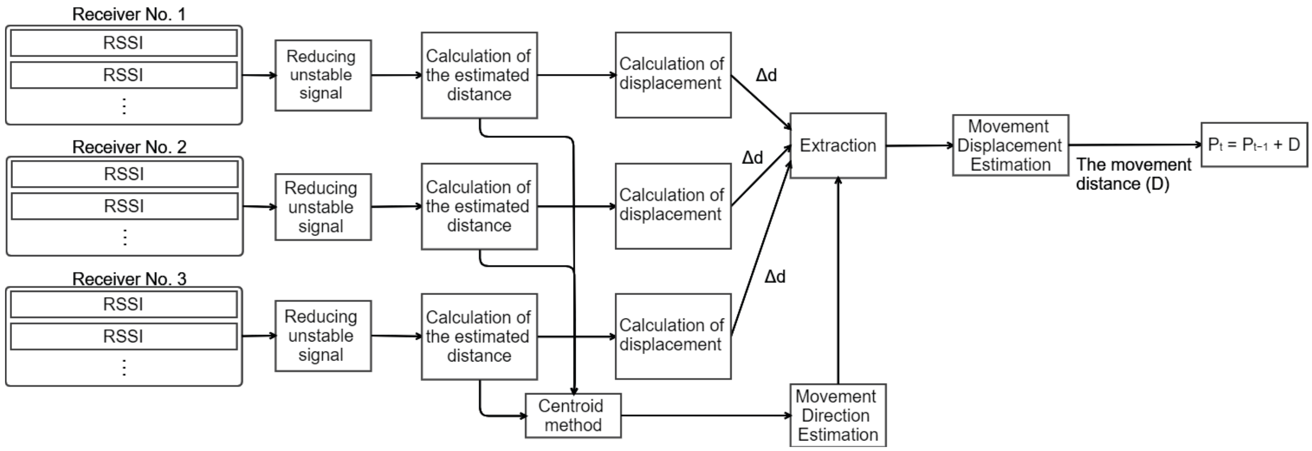

Fig. 3. The flow of the proposed method

C. Experiment

Experiments were conducted to verify whether this method could reduce the effect of a human body. In the experiment, three receivers were installed at the 0 m, 10 m, and 20 m points, and walked from the 0 m point to the 20 m point at a constant speed, then turned around and returned to the 0 m point. A person has a beacon at his/her chest. The estimated positions of the Centroid method and the estimated positions of the proposed method are plotted in Figure 4.

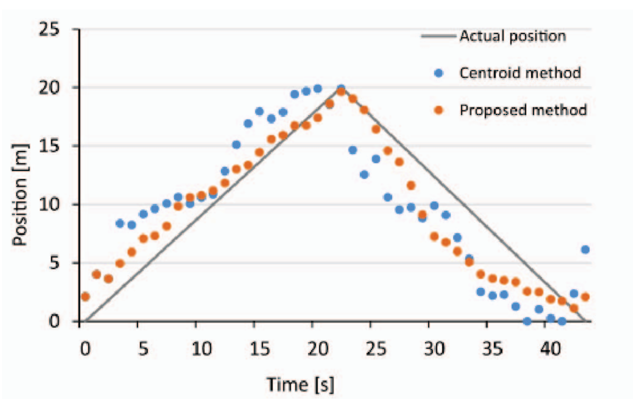

Fig. 4. Results of the proposed Method and Centroid Method

Figure 4 shows that the position estimated by the proposed method is closer to the actual position than the position estimated by the Centroid method. When the beacon is at the chest position, signals opposite to the move direction are affected by a human body. In the Centroid method, the estimated position is estimated ahead of the actual position affected by a human body. Figure 4 shows that the proposed method reduces the effect of a human body and can estimate the position close to the actual position.

In this experiment, the accuracy of Movement Direction Estimation was 95.7%. The mean error of the proposed method was 1.83m, which reduced the mean error by 41.2% compared to the Centroid method.

However, the experimental results in Figure 4 show that the error increases from around 28 seconds. This is because the movement displacement is estimated larger than the actual displacement between 27 and 29 seconds. As the result of the errors accumulated, there were large errors in the estimated positions at around 30 seconds.

VI. Correction of Accumulated Error

To reduce the effect of accumulated errors, we detect the passing of a receiver and corrects the position. We use two methods for detecting a passing of a receiver: one is to use the fact that the signal affected by a human body changes before and after passing through a receiver's position, and the other is to use historical data. If passing through a receiver cannot be detected by the former method, it is detected by the latter method.

A. Using the Change of Signals

The signal affected by a human body changes before and after passing through a receiver's position. Figure 5 shows the results of measuring the change in RSSI when a person has a beacon at his/her chest. The person passes through a receiver at 4.3 second. Figure 5 shows that RSSI increases before 4 seconds but decreases after 4 seconds. This is because a beacon is had at the chest, so it receives signal not affected by a human body before they pass through a receiver, but affected by a human body after they pass through the receiver.

Three conditions were set up to detect the passage of a receiver.

Conditions 1
: The displacement at time $t-1$ and time t is opposite.

Conditions 2
: The estimated distance between a beacon and a receiver is within 1m.

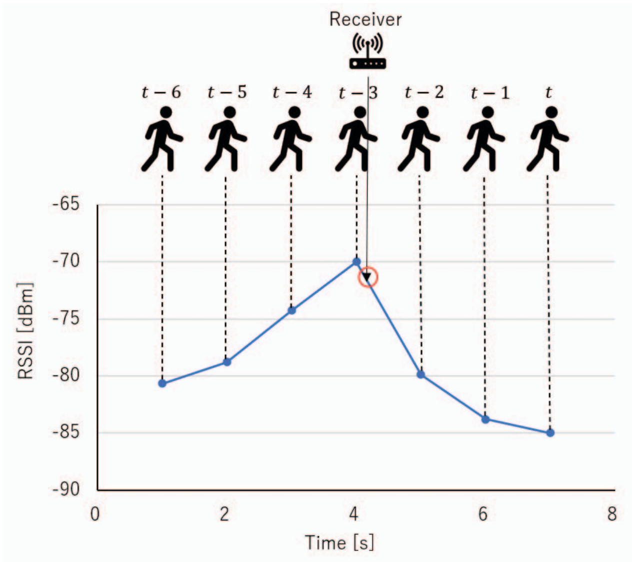

Fig. 5. RSSI Before and After Passing a Receiver

Conditions 3

An absolute value of the displacement of time t compared with one at time $t-1$ is relatively big.

Condition 1 is that the displacement of the estimated distance at time $t-1$ and time t are opposite. The estimated distance gets closer to a receiver before passing, but, through a receiver the estimated distance goes away after passing. Therefore, the displacement is reversed before and after passing through a receiver.

Conditions 2 is that the estimated distance between a beacon and a receiver is less than 1 m. This prevents false detection at a position where is not in close to a receiver.

Conditions 3 determines the likelihood of passing a receiver by comparing the absolute value of the displacement at time $t-1$ and at time t. When a person has a beacon is at his/her chest, the signal is not affected by a human body before passing through a receiver. In contrast, after passing through a receiver, the signals are affected by a human body and are attenuated. Thus, an absolute value of the displacement of time t compared with one at time $t-1$ is relatively big.

When all of these conditions are satisfied, we determine the receiver to be passed. Note that the remained 35.0% does not fail; it is just undetected. When a receiver passed is detected, the estimated position is the position where the receiver is installed.

B. Using Historical Data

When a certain period of time p_t (we set p_t to 5 seconds) elapses after an estimated position of the Centroid method passage through a receiver, we judge the passage of a receiver cannot be detected in Section VI-A. Then, we collect the displacement of $p_t \times 2$ seconds (here, 10 seconds because p_t is 5).

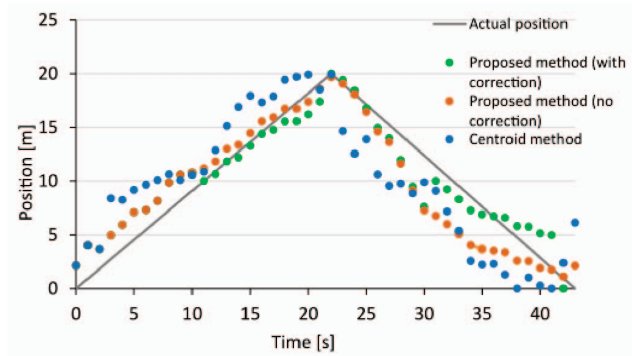

Fig. 6. Comparison of position estimation results with corrections

From their displacement, we extract only which matches Condition 1 in Section VI-A. In the extracted displacements, select the displacement with the smallest distance of the estimated distance (d_t in (13)) used to calculate the displacement. The time of the selected displacement is determined to be the time when it passed through a receiver. In this method, 85.7% of the 35.0% undetermined in Section VI-A can be detected correctly. Thus, 95% (65.0% + 35.0% × 85.7%) can be detected correctly (5% fails).

When the passage of a receiver is detected, an estimated position P_{t-n} is corrected to the receiver's position (P'_{t-n}). The estimated positions the $t-n$ are corrected by adding the difference between P'_{t-n} and P_{t-n}.

C. Experiment

We conducted experiments to verify whether the accumulated errors can be reduced by detecting the passage of a receiver. Figure 6 shows a plot of the estimated positions of the Centroid method, the estimated positions of the proposed method without the corrections, and the estimated positions of the proposed method with corrections.

As shown in Figure 6, the estimated positions of the proposed method with corrections can estimate the position closer to the actual position than the estimated position without correction. The mean error is reduced by 59.1% compared to the Centroid method and 24.7% compared to the one without correction.

VII. Conclusion

In this study, we attempted to reduce the error caused by a human body by using the displacement. As a result, we succeeded in reducing the error caused by the effect of a human body compared with the Centroid method. As future works, it is necessary to conduct experiments with other beacons and to install the receiver not only a straight line but also a plane area.

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