RSSI-Ranging Method Using Pattern Diversity and Distance-Based Reliability Function

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Abstract. This paper studies the accuracy improvement of the localization technique based on the received signal strength indicator (RSSI)-ranging using Bluetooth, which has been commonly used for an indoor localization. In our system, a transmitter diversity technique is introduced, where a beacon transmits four different ID signals with four different radiation patterns. A smartphone is used as a receiver, and detects the signal with the strongest RSSI among all beacons. The most likelihood detection is used to improve the localization accuracy, where the close beacon is trusted more than the distant one. The experiment revealed that our diversity scheme improves the average and median localization errors by 1.22 m and 1.86 m, respectively. The most likelihood detection considering the distance realizes 6.70 m and 4.62 m accuracy in average and median values, respectively.

Keywords: RSSI-ranging · Array antenna · Bluetooth.

1 Introduction

The indoor localization techniques using Bluetooth Low Energy (BLE) beacons have been widely studied [1]. For this application, the beacons must be low cost, low-power consuming, and easy-to-install. On the other hand, the currently available BLE beacons can only support an Received Signal Strength Indicator (RSSI), which is the signal strength information. A localization method called RSSI-ranging [2] using the RSSI has been widely studied. However, RSSI rapidly fluctuates by location due to the multipath-fading effect, and it is difficult to estimate the accurate distance only from the RSSI. As a more accurate localization method, DOA/DOD (Direction-of-Arrival/Departure) estimation method [3]-[4] has been studied. In the methods [4] , the arrival / departure direction is estimated from the correlation matrix of the array response using 90 degree and 180 degree hybrid circuits and an array antenna. However, when there is large errors

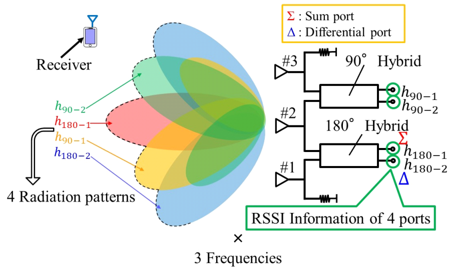


Fig. 1. RSSI-ranging using pattern diversity

in estimated DODs due to multipath-fading effect, the localization accuracy is extremely lowered. The alternative wireless method is epitomized by the fingerprinting technique [5] . This method can identify the location accurately, but the RSSI-distribution database needs to be created before the localization. Moreover, the database is easily outdated and needs to be rebuilt if the arrangement of the furniture in the environment is changed. For there reasons, the radio-wave-based robust technique for improving localization accuracy is needed.

In this research, we propose a method to improve localization accuracy by introducing RSSI-ranging with a pattern diversity and distance-based reliability function technique. The experiment in the indoor environment was carried out to verify the accuracy of the proposed method, and its performance compared to the conventional methods are discussed.

2 RSSI-Ranging Method Using Pattern Diversity and Distance-Based Reliability Function

In this section, we will show the method to improve the localization accuracy using RSSI-ranging with pattern diversity and distance-based reliability function. RSSI-ranging is performed using received signals transmitted from multiple beacons. However, the estimated distance for each beacon is not accurate due to the multipath fading. The pattern diversity is introduced to improve the ranging accuracy by alleviating the multipath effect. The reliability function is used to take multiple ranging results into account when each result has a high ambiguity in distance. The following discussions explain how these issues are managed in this study.

2.1 RSSI-Ranging Method Using Pattern Diversity

In the proposed method, The RSSI-ranging is performed using the RSSI observed at the terminal. In order to consider the ambiguity in the estimated distance, a evaluation function based on a Gaussian function is used, and the sum of the evaluation function corresponding to all beacons is used to enhance the localization accuracy. A conceptual sketch of the RSSI-ranging using a pattern diversity is shown in Fig. 1. In this study, the multibeam feed network developed in our previous work [4] is used to obtain a high directive gain over the wide angular range. A 180-degree hybrid is used for the pensile and V-shaped patterns. A 90-degree hybrid is used for left and right directed patterns. The combiners are connected to the antennas, and collect the signals from both hybrids. To maintain the radiation pattern, the dummy loads are used at both sides of the circuit because the unwanted reflection from the circuit ends will affect the radiation patterns. As shown in Fig.1, the envelope directivity covers wide directions while each pattern has a high gain as well as the narrow beam suitable for rejecting the unwanted multipaths. Note that this circuit functions almost identically for all frequencies transmitted by the beacon signal generators because the hybrid bandwidth is much wider than the used frequency bandwidth ($\simeq$3%). In the proposed method, the beacon signals emitted from a 3-element array antenna with 4 different patterns are received by a commercially available smartphone. The RSSI-ranging is performed by choosing the most strongest RSSI among all patterns. This idea contributes to avoiding the signal strength dips due to the multipath fading, and the distance can be estimated stably.

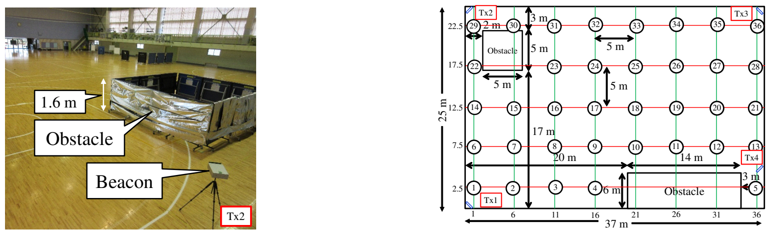
2.2 Distance-Based Localization Using Reliability Function

Even though the RSSI-ranging accuracy is improved by using the pattern diversity technique, there still exists ambiguity in the estimated distance. The RSSI-ranging method tends to incur a large error due to multipath-fading effect especially when the distance between the beacon and terminal is large. To mitigate the effect of the fading on the localization, the beacon with higher RSSI is more trusted than other beacons, and this idea realizes further improvement in the localization accuracy. The second key idea is a weighting scheme, which is introduced to consider the reliability of the estimated distances from all beacons. An evaluation function based on a Gaussian function is introduced to consider the ambiguities in the estimated distance. In this scheme, the higher reliability value is given for the closer beacon, while the lower value is given for the distant beacon. The distance-based reliability function W is defined as the reciprocal of the power p of the estimated distance. p corresponds to the path-loss and this is the simplest path-loss model commonly used in the various situations including the indoor and outdoor environments [6],[7] . In the proposed method, p is experimentally determined in advance. The evaluation functions corresponding to all beacons are weighted by the reliability coefficient and summed to calculate the total evaluation function.

$$F_{ranging} = \sum_{n=1}^{N} W(n) f_{ranging}(n) \tag{1}$$

Where, N is the number of Tx and $f_{ranging}$ is evaluation function of RSSI-ranging. The summation operation is used to take all evaluation functions into account. The multiplication is not used because the correct solution disappears if one of the functions strays significantly. Finally, the receiver's location is estimated by searching the point, where the sum evaluation functions is maximum.

3 Experiment



(a)Experimental environment (b)Measurement point and coordinates

Fig. 2. Experiment setup

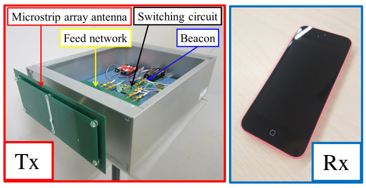


Fig. 3. Used transmitter and receiver

3.1 Experimental Conditions and Environment

In this experiment, we performed indoor localization experiment using the BLE beacons and smartphone terminal, and evaluated the localization accuracy. To verify the performance of the ranging scheme without the effect of the human body, we conducted the experiment with holding the terminal above the head of a person. The receiver's height is about 2 m. The experiment environment is detailed in Fig. 2. This experiment was conducted in a 25 m $\times$ 37 m indoor environment. The measurements were performed at 36 points at 5 m interval in both vertical and horizontal directions. The metallic obstacles are intentionally located to consider the effect of scatterers whose heights are about 1.6 m. The beacon transmitters were placed at the four corners of the measurement area. The locations of the transmitters are Tx1 (0.57 m, 0.55 m, 2.91 m), Tx2 (0.58 m, 24.5 m, 1.65 m), Tx3 (36.5 m, 24.4 m, 1.65 m), Tx4 (36.4 m, 6.55 m, 1.65 m). Besides, All transmitters direct the center of the measurement area. Fig. 3 shows a photo of the beacon transmitter and receiver used in the experiment.

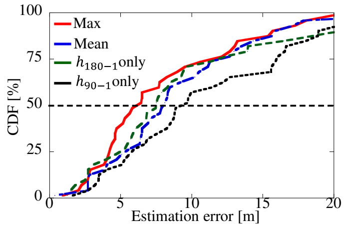


Fig. 4. CDF of localization error with and without diversity effect

The receiver is commercially available smartphone without any alteration. As a transmitter, we used a device, which has a 3-element patch array antenna and transmits 4 beacon signals with 4 different patterns. 4-port feed network is connected to the transmitter via SP4T switch and the signal is sequentially switched all ports. The set of the beacon signal consists of 3 frequencies (advertising channels), i.e. 2.402 GHz, 2.426 GHz, and 2.480 GHz, and is transmitted by every 20 ms.

3.2 Result 1: Performance of Pattern Diversity

Fig. 4 shows the cumulative distribution function (CDF) of the localization error with the diversity scheme. We also show the CDFs of the localization errors when RSSI-ranging is performed using the average of all ports, only port h_{180-1}, and only port h_{90-1} instead of the diversity scheme. The average and median localization errors of the mean-RSSI based ranging are 8.89 m and 7.99 m, respectively. On the other hand, the average and median localization errors of the diversity scheme are 7.77 m and 6.13 m, respectively. Therefore, it is found that the localization accuracy can be improved by selecting the port with the highest RSSI. Note that the diversity scheme described above is adopted in the following results.

3.3 Result 2: Effect of Distance-Based Reliability Function on Localization Accuracy

The localization using the evaluation functions discussed above was evaluated, where the average of the Gaussian function is 0, and the variance is set to 100 m in this evaluation. In the proposed method, the constant p must be determined in advance of the localization. In this study, the two values, $p = 0$ and $p = 0.8$, were tested, where $p = 0$ means all estimated distances are equally trusted because weighting value is always 1 independently to the distance. Fig. 5 shows CDF of localization errors when $p = 0.8$ and $p = 0$. When the value is set to $p = 0$, the average and median errors are 7.77 m and 6.13 m, respectively. When the value is set to $p = 0.8$, the average and median errors are improved to 6.70 m and 4.62 m, respectively.

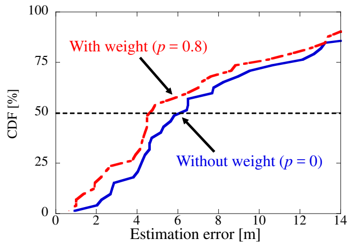


Fig. 5. CDFs of localization error with and without reliability weighting technique

4 Conclusion

This paper has studied the accuracy improvement method of the RSSI-ranging based localization, where the pattern diversity and distance-based reliability function are jointly used. The experiment in the indoor environment revealed that the average and median errors are improved by 1.22 m and 1.86 m, respectively, compared to that of the non-diversity scheme. Moreover, the distance-based reliability function improves the average and median errors by 1.07 m and 1.51 m, respectively. Currently, the combination of the proposed method and DOD-based localization is experimentally studied for the further accuracy improvement, and a part of this result will be presented in the conference.

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