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# A Preliminary Cut-off Indoor Positioning Scheme considering the Reference Points with the Same Signal Similarity

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**Abstract**

The preliminary cut-off indoor positioning scheme estimates user's position using relative ranks of the peak of signal strength received from nearby beacons. First, a cut-off fingerprint map composed of only the reference points in the fingerprint map the same as the beacons data received in real-time is constructed. The user's position can be estimated in two ways depending on the number of reference points in the cut-off fingerprint map. Firstly, when the number of candidate reference points is less than and equal to a predefined number, the center of the reference points is the estimated user's position. Secondly, when the number of candidate reference points is larger than the predefined number. In this case, the similarity between the reference points in the cut-off fingerprint map and the data from the user device in real-time is calculated. After extracting a predefined number of reference points with high similarity, the center of the points is calculated as estimated user's position. However, since this scheme always estimates the center of the reference points of the cut-off fingerprint map as the user's position, the error increases as the number of reference points increases. This results in lower accuracy. In order to improve the accuracy, we propose a preliminary cut-off scheme considering the reference points with the same signal similarity. Experimental results show that the proposed scheme has better accuracy than the previous scheme.

**Keywords**: Indoor Positioning, Fingerprint map, Cut-off, Beacon, Reference point, Similarity

## INTRODUCTION

Indoor positioning scheme using fingerprint map has an off-line phase and an on-line phase. KNN (K-Nearest-Neighbor) algorithm [1] is a representative algorithm among indoor positioning scheme using fingerprint map. In off-line phase, a fingerprint map is constructed. In on-line phase, user's position is estimated by comparing RSSI (Received Signal Strength Indication) received in real-time with RSSI stored in the fingerprint map. We proposed the preliminary cut-off indoor positioning scheme using fingerprint map [2]. This scheme utilizes the relative ranks of the peak RSSI in the off-line and on-line phase to compensate for signal variability and instability. In off-line phase, the peak RSSI received from the nearby beacons at each RP (Reference Point) in the fingerprint map and the relative ranks of the peak are stored. In on-line phase, user's position is estimated by comparing the data received from the nearby beacons in real-time with the data stored in the fingerprint map. First, a cut-off fingerprint map composed of RPs storing beacon data identical to beacon data received in real-time is created. If the number of RPs in the cut-off fingerprint map is less than or equal to K, the center of the RPs is estimated as the user's position. The K is the number of RPs similar to the data received in real-time and is defined in advance. These K RPs are called the nearest neighbors. On the contrary, when the number of RPs in the cut-off fingerprint map is larger than K, K RPs are extracted through the similarity between the ranks of the data received in real-time and the RP stored in cut-off fingerprint map. The center of the extracted K RPs is estimated as the user's position.

Since the preliminary cut-off scheme always estimates the center of K or less RPs as user's position, there is a problem that error always occurs when the number of RPs of the cut-off fingerprint map is two or more. Therefore, we propose a preliminary cut-off scheme considering the reference points with the same signal similarity. This scheme uses the similarity between the ranks stored in less than K RPs and the ranks of data received in real-time. We have conducted experiments to evaluate the accuracy of the proposed scheme and the previous scheme. Experimental results show that the preliminary cut-off scheme considering the reference points with the same signal similarity is more accurate than the previous scheme.

## RELATED WORK

KNN algorithm constructs a fingerprint map using the RSSI value itself in off-line phase. In on-line phase, the Manhattan distance between RSSI received in real-time and all RSSI stored in the fingerprint map is calculated using the Manhattan distance calculation. User's position is estimated using K RPs with the shortest distance.

The preliminary cut-off scheme uses beacons. In off-line phase, the relative ranks of the peak RSSI received from the nearby beacons in each RP rather than the RSSI itself is used. In on-line phase, first, a cut-off fingerprint map consisting of only RPs having the same data as the beacon data received in real-time is created. If the number of RPs in the cut-off fingerprint map is K or less, the center of the RPs is estimated as user's position. However, if there are more than K, the similarity between the relative ranks stored in the RPs in the cut-off fingerprint map and the relative ranks of data received in real-time is calculated. The similarity is calculated using Spearman's footrule method. After extracting the K RPs having the greatest similarity, the center of the extracted RPs is estimated as user's position.

[3] is a study on a method of cutting-off data stored in a fingerprint map. When constructing a fingerprint map, the time to scan the signal of the nearby beacon at each RP is longer than the time the user scans the signal in real time. In [3], the scan time for each RP to construct a fingerprint map is set to 30 seconds and the scan time for real-time is set to 1 second. Some problems can arise due to different scan times. The first problem is that when signals of nearby beacons is scanned for 30 seconds at any RP to construct a fingerprint map, the number of RSSIs received from a specific beacon may be relatively small. In this case, when the user scans for one second in real time, there is a possibility that the beacon signal is not received. As a result, the estimation probability is low, and even if estimation is possible, it has low accuracy. In [3], beacons receiving RSSIs less than a specific number based on the average number of RSSIs scanned from each beacon for 30 seconds are excluded when constructing a fingerprint map. The second problem is that even if the beacon signal is scanned at the same position, the beacon data scanned when scanning for 30 seconds and 1 second may be different. If signals are scanned from many beacons in any RP, relatively low-ranked beacons may be far from the scan position or there may be an obstacle in the middle. In this case, when scanning for one second, there is a possibility that signal of the beacons is not received. In [3], the maximum number of beacons stored in each RP of the fingerprint map is determined and configured.

[4] is a study on a method of combining many fingerprint maps into one. First, a process of constructing a fingerprint map using the method of [3] is performed several times to construct a plurality of fingerprint maps. Next, the rank pattern stored in each of the RPs of the plurality of fingerprint maps is confirmed. And stores the most frequently generated rank pattern as the rank pattern of the corresponding RP of the last fingerprint map. This process is performed for all the RPs to form the last fingerprint map that is combined with a plurality of fingerprint maps.

## A PRELIMINARY CUT-OFF INDOOR POSITIONING SCHEME CONSIDERING THE REFERENCE POINTS WITH THE SAME SIGNAL SIMILARITY

Figure 1 shows a step-by-step process of estimating a user's position using the preliminary cut-off scheme. The fingerprint map is constructed based on the results of [3] and [4]. First, it receives RSSI and beacon data from nearby beacons through the user's device. And it calculates the peak RSSI of the nearby beacons. Next, a cut-off fingerprint map consisting of only the RPs and beacons of the fingerprint map storing the same data as the beacon data received in real-time is created. Therefore, the cut-off fingerprint map consists only of the RP and the beacon storing the same data as the beacon data received in real-time. Then, the number of RPs (number of columns, S) of the cut-off fingerprint map is calculated. And the number of nearest neighbors (K) considered for estimation is predefined. If S is greater than K, the similarity between relative ranks of the peak of RSSI received from nearby beacons in real-time and relative ranks stored in each RP of the cut-off fingerprint map is calculated. The K RPs with high similarity are extracted. In order to calculate the similarity, Spearman's footrule method is used according to the result of [5]. [5] includes a study of errors that occur when various similarity calculation methods are used. As a result, when using Spearman's footrule method, the error is the smallest. On the contrary, when S is less than K, S RPs are determined to be sufficiently adjacent and are selected as the nearest RP. If the nearest RPs are selected according to the above two cases, the center of the RPs is estimated as user's position. However, since the center point of the nearest RPs is always estimated as user's position, there is a problem that an error always occurs except when S is 1.

```
1)  Receive RSSI from nearby beacons by user's device
2)  Identify UUID of the beacons
3)  Find the peak RSSI received from each beacon
4)  Construct a cut-off fingerprint map consisting of only
    the RPs storing data the same as the beacon data of
    step 2
    Let the number of the RPs be S which is the number
    of columns in the cut-off fingerprint map
5)  if S > K  // K is the predefined number of the nearest
              // neighbors to be considered for estimation
6)      Calculate relative ranks of the peak RSSI obtained
        in the step 3
7)      Calculate the similarity between the relative ranks of
        step 6 and the ranks of S RPs
8)      Select K RPs from S RPs according to higher
        similarity
9)      Estimate the center of K RPs as user's position
10) end if
11) else // S <= K
12)     Estimate the center of S RPs as user's position
13) end else
```

**Figure 1.** The preliminary cut-off indoor positioning scheme

Figure 2 shows the preliminary cut-off scheme considering the RP with the same signal similarity that compensates for the problem of the previous scheme mentioned above. This scheme calculates the similarity not only when S is greater than K but also when K is less than K. The smaller the similarity, the more similar the two data are. Thus, a similarity of 0 means that both two data are identical. Then, the number (T) of RPs having a similarity of 0 is found. If T is 0, it means that there is no RP having the same rank of the peak RSSI of the real-time data and the peak RSSI stored in the RP of the cut-off fingerprint map. Therefore, in this case, the center of the S RPs is estimated as user's position. For example, when S is 2, the previous scheme estimates the center of the two RPs as user's position. However, the preliminary cut-off scheme considering the RP with the same signal similarity calculates the similarity between the relative ranks stored in the two RPs of the cut-off fingerprint map and the relative ranks of the data received in real-time. Then, when T is 0, the center point of the S RPs is estimated as user's position. However, if T is greater than or equal to 0, the center point of T RPs is estimated as user's position. For example, if T is 1, the RP is estimated as user's position because there is only one RP having the same data as the data received in real-time. If T is 2 or more, the center of T RP is estimated as user's position because there are two or more RPs having the same data as the data received in real-time. As a result, the preliminary cut-off scheme considering the RP with the same signal similarity has higher accuracy than the previous scheme.

```
1)  Receive RSSI from nearby beacons by user's device
2)  Identify UUID of the beacons
3)  Find the peak RSSI received from each beacon
4)  Calculate relative ranks of the peak RSSI obtained in the
    step 3
5)  Construct a cut-off fingerprint map consisting of only the
    RPs storing data the same as the beacon data of step 2.
    Let the number of the RPs be S which is the number of
    columns in the cut-off fingerprint map.
6)  if S > K  // K is the predefined number of the nearest
              // neighbors to be considered for estimation
7)      Select K RPs from S RPs according to higher similarity
        S = K
8)  end if
9)  Calculate the similarity between the relative ranks of step
    4 and the relative ranks of S RPs
10) Find RPs (Let the number be T) with similarity of 0 among
    S RPs
11) if T = 0 // there is no RPs with the same RSSI as the user's
12)     Estimate the center of S RPs as user's position
13) end if
14) else
15)     Estimate the center of T RPs as user's position
16) end else
```

**Figure 2.** The preliminary cut-off indoor positioning scheme considering with the same signal similarity

## PERFORMANCE EVAULATION

Figure 3 shows the experimental environment in which beacons and RPs are arranged to construct a fingerprint map. The experiment was actually conducted on the third floor of our university building. Symbols Ⓐ ~ Ⓜ in Figure 3 indicate beacons, and numbers 1 ~ 21 indicate RP numbers. The experimental environment is 72m in width and 34m in length. The space between beacons is 10m and the space between RPs is 5m. The distance between the beacons and RP is 3m and 2m. For example, the distance between beacon A and RP 1 is 3m and the distance between beacon B and RP 2 is 2m. The distance between the beacon and the RP is based on the results of the research in [6].

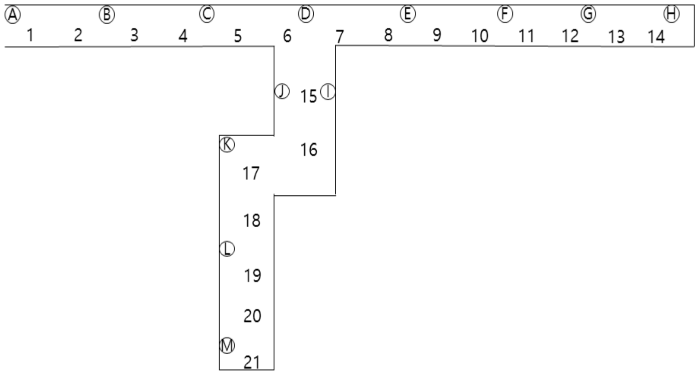


**Figure 3.** Experiment Environment

Table 1 is a fingerprint map constructed according to the results of [3] and [4]. In table 1, column shows RP number and row shows beacon data. Table 1 shows the relative rank of the peak RSSI of beacons received at each RP.

**Table 1.** A Fingerprint map constructed at Fig.3

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | | | | | | | | | | |
| 2 | 2 | 1 | 3 | 4 | | | | | | | | | |
| 3 | 3 | 1 | 2 | 4 | | | | | | | | | |
| 4 | 4 | 2 | 1 | 3 | | | | | | | | | |
| 5 | 5 | 3 | 1 | 2 | | | | | 4 | | | | |
| 6 | | | 2 | 1 | 5 | | | | 3 | 4 | | | |
| 7 | | | 4 | 1 | 2 | | | | 3 | 5 | | | |
| 8 | | | | 2 | 1 | 3 | | 5 | | 4 | | | |
| 9 | | | | 5 | 1 | 2 | 3 | 4 | | | | | |
| 10 | | | | 5 | 2 | 1 | 4 | 3 | | | | | |
| 11 | | | | | 4 | 1 | 2 | 3 | | | | | |
| 12 | | | | | 4 | 2 | 1 | 3 | | | | | |
| 13 | | | | | 4 | 3 | 1 | 2 | | | | | |
| 14 | | | | | | 3 | 2 | 1 | | | | | |
| 15 | | | | 3 | | | | | 1 | 2 | | 4 | 5 |
| 16 | | | | 4 | | | | | 1 | 2 | 3 | 5 | |
| 17 | | | | | | | | | 4 | 5 | 1 | 2 | 3 |
| 18 | | | | | | | | | 4 | | 2 | 1 | 3 |
| 19 | | | | | | | | | 4 | | 3 | 1 | 2 |
| 20 | | | | | | | | | | | 3 | 2 | 1 |
| 21 | | | | | | | | | | | 3 | 2 | 1 |

Figure 4 shows 10 arbitrary user locations for actually positioning estimation experiments. In the figure, (1) to (10) show arbitrary user locations where the positions are estimated by the proposed algorithm in this paper.

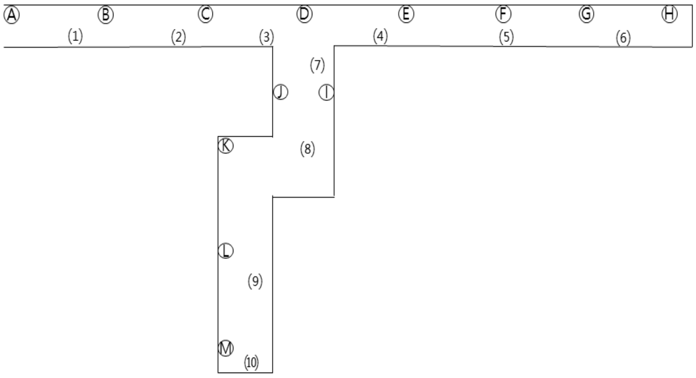


**Figure 4.** Arbitrary user locations to be estimated

Figure 5 is a graph showing the average error between arbitrary user location and estimated location when 10 times of 10 arbitrary user location in Figure 4 are estimated. The horizontal axis in Figure 5 represents 10 arbitrary user locations, and the vertical axis represents the average errors when 10 times at each position.

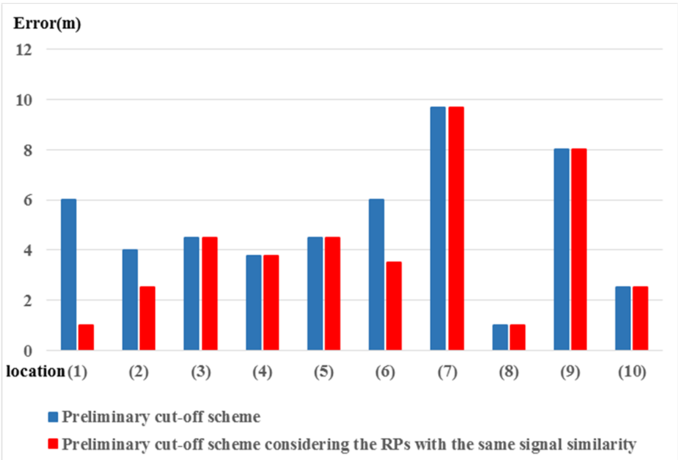


**Figure 5.** Comparing the accuracy of the preliminary cut-off scheme considering the RP with the same signal similarity and the previous method

The average error for all user locations is about 4.75m and about 3.8m, respectively, in the preliminary cut-off scheme considering the RP with the same signal similarity and the previous method. Each location can be divided into a location where the error is improved and where the error is identical than the previous method. First, the arbitrary user locations (1), (2), and (6) show the improved error when using the preliminary cut-off scheme considering the RP with the same signal similarity than the previous scheme. In particular, it can be seen that the error is significantly improved at user location (1). Table 2 shows the data received via the user's device at arbitrary user location (1).

**Table 2.** Data received from the user location (1)

| BC | A | B | C | D |
|---|---|---|---|---|
| Rank | 2 | 1 | 3 | 4 |

Based on the information in Table 2, a cut-off fingerprint map as shown in Table 3 is created.

**Table 3.** Cut-off fingerprint map to estimate user location (1)

| RP \ BC | A | B | C | D |
|---|---|---|---|---|
| 2 | 2 | 1 | 3 | 4 |
| 3 | 3 | 1 | 2 | 4 |
| 4 | 4 | 2 | 1 | 3 |

The previous scheme at user location (1) uses the center of RP 2, 3, and 4 in Table 3. Since the distance between RPs is constant, RP 3, which is the center of RP 2, 3 and 4, is estimated as user's position. However, the preliminary cut-off scheme considering the RPs with the same signal similarity calculates the similarities between the ranks in Table 2 and the RP 2, 3, and 4 ranks in Table 3, respectively. Then, the process of calculating the number of RPs with similarity of 0 is executed. As a result of this process, there is RP 2 with similarity of 0. Therefore, RP 2 is estimated as user's position. In fact, it can be seen from Figures 3 and 4 that the RP closest to user location (1) is RP 2. Table 4 shows data received via the user's device at arbitrary user location (2).

**Table 4.** Data received from the user location (2)

| BC | A | B | C | D |
|---|---|---|---|---|
| Rank | 4 | 2 | 1 | 3 |

The cut-off fingerprint map of user location 2 is the same as Table 3. The estimation result of the previous scheme is RP 3. However, the estimation result of the preliminary cut-off scheme considering the RP with the same signal similarity is RP 4. Actually, the RP closest to user location (2) is RP 4. Table 5 shows the beacon data received via the user's device at the arbitrary user location (6). Table 6 shows a cut-off fingerprint map based on the beacon data received at arbitrary user location (6).

**Table 5.** Data received from the user location (6)

| BC | E | F | G | H |
|---|---|---|---|---|
| Rank | 4 | 3 | 1 | 2 |

**Table 6.** Cut-off fingerprint map to estimate user location (6)

| RP \ BC | E | F | G | H |
|---|---|---|---|---|
| 11 | 4 | 1 | 2 | 3 |
| 12 | 4 | 2 | 1 | 3 |
| 13 | 4 | 3 | 1 | 2 |

The previous scheme at arbitrary user location (6) uses the center of RP 11, 12, and 13 in Table 6. Therefore, RP 12 is estimated as user's position. However, the preliminary cut-off scheme considering the RP with the same signal similarity estimates RP 13 as user's position. Actually, the RP closest to user location 6 is RP 13. The others except for the user locations (1), (2), and (6) show the same average error as the previous scheme. There are two cases where the two schemes show the same average error. The first is for a cut-off fingerprint map with one RP. The second is a case where the number of RP with similarity of 0 for all RPs of the cut-off fingerprint map is zero. In these two cases, the preliminary cut-off scheme considering the RP with the same signal similarity estimates the position by the same process as the previous scheme. Therefore, the average error shows the same result. As a result, the preliminary cut-off scheme considering the RP with the same signal similarity improves the accuracy by about 20% compared to the previous scheme.

## CONCLUSION

We propose a preliminary cut-off indoor positioning scheme considering the RP with the same signal similarity to improve accuracy more than the previous cut-off indoor positioning scheme. This scheme does not always estimate the user's position to the center of the RPs of the cut-off fingerprint map. The similarity between the ranks of the data received in real-time and the ranks of the RPs of the cut-off fingerprint map is calculated. Then, the user's position is estimated in consideration of the number of RPs with the similarity of 0. If the RP with the similarity of 0 is zero, the user position is estimated with the center of the RPs of the cut-off fingerprint map. On the contrary, when the number of the RPs is greater than zero, the center of the RPs with the similarity of 0 is estimated as user's position. If there is one RP with a similarity of 0, it is determined that the data of the corresponding RP is the same as the data in real-time, and the RP is estimated as user's position. There are cases where the preliminary cut-off scheme considering the RP with the same signal similarity and the previous scheme have the same average error. However, we have confirmed that the preliminary cut-off scheme considering the RP with the same signal similarity has about 20% higher accuracy than the previous scheme. Furthermore, it is necessary to study how to reduce the error even when there are zero or more RPs with similarity of 0. In this case, it is not always necessary to estimate the center point as the user position, but it is possible to obtain a higher accuracy by estimating with a finer process.

## ACKNOWLEDGEMENTS

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