Particle Filter to the indoor localization with Finger Print designed for wide coordinate interval.

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Abstract: Currently, many researches are proceeded on location estimation using wireless LAN access points. In this research, we apply a particle filter, which is one of the time series filters, to examine the design method of its parameters and evaluate its accuracy. As a result of adjusting the parameters in the proposed method, the estimation error could be reduced. It was also confirmed that the proposed method can improve the accuracy more than the conventional method even if the DB coordinate interval increases.

Keywords: Particle Filter, Wireless LAN, Finger Print, location estimation
Classification: Navigation, guidance and control systems

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1 Introduction

Since GPS estimates a location using radio waves from satellites, there is a drawback that accuracy is reduced in environments such as indoors and underground malls where radio waves cannot be received directly. Therefore, in this laboratory, we are studying location estimation by Finger Print using wireless LAN access points (APs).

However, the Finger Print estimation is performed using only the data at the time when the user measures, so a large estimation error may occur momentarily if the user is between the coordinates. Therefore, in this research, user data is treated as time-series data. Furthermore, the Particle Filter, which is one of the time-series filters, is applied to Finger Print to improve the accuracy.

2 Finger Print

At a preparation stage of the Finger Print, a service provider measures RSSI (Received Signal Strength Indicator) on predetermined coordinates, and creates a DB (database) of data sets of RSSI from each AP on the coordinates. At an estimation stage, UD (user’s measurement data) is compared with the DB. Then, the coordinate with the smallest difference is used as the estimation result [1].

The Mean Squared Error (MSE) of RSSI is sometimes used as the degree of difference when comparing DB and UD.

In case of few APs commonly observed by DB and UD, if the RSSIs of the few APs become close to each other, MSE becomes small and the estimation error may become large. To prevent this, we define the AP coincidence rate (APCR) commonly observed in DB and UD and narrow it down accordingly [2].

3 Problems in Finger Print

Problems in Finger Print include high measurement cost and large instantaneous error. It is necessary to create a DB with more coordinates and finely measure the coordinate intervals to improve the accuracy. However, many DB coordinate measurements increase the measurement cost accordingly. On the contrary, if the number of measurement coordinates is small, the measurement cost is reduced. However, since the coordinate interval becomes wider, the distance from the DB coordinate to the estimated position increases, and the accuracy decreases. In addition, only the data at just the time when the user measured is utilized in the Finger Print. The data before and after measurement are not considered. Therefore, the estimation result may be estimated at a point that is abruptly separated, and may be estimated at the original position in the next estimation. However, since the user's position is continuous in time, such estimation results are wrong.

As methods to eliminate such problems, methods of weighting and averaging estimated coordinates by their existence probabilities [3] and methods of treating user data as time series data are being studied.
4 Time series filters

4.1 Overview

The time series filter is a theory that has been originally researched in the field of control theory. There are problems such as predicting future values from past observed signal series and estimating target states from observed values including noise [4]. There are Kalman Filter and Particle Filter as one of the time series filters.

The Kalman Filter is a method for estimating the system state from the past (one frame before) estimated value, the current input to the system, and the value measured from the system [5]. The Kalman Filter can be predicted by a simple linear calculation, has a small amount of calculation, and is stable. However, there is a constraint that the system model and the observation model must be linear.

4.2 Particle Filter

A Particle Filter (Monte Carlo filter) is a method that estimates the internal state based on observation data and a model while adding noise to multiple particles. Since the amount of calculation is determined by the number of particles, faster processing is possible depending on the number of particles. It is also suitable for real-time processing because it simultaneously processes detection and recognition.

In related research, there is a method of modeling the radio wave environment of a wireless LAN access point by GMM (Gaussian Mixture Model) and estimating the position by combining the GMM and Particle Filter [6]. In that method, first, wireless LAN radio wave information is collected at many points. The collected radio wave information is converted into a two-dimensional point distribution and a GMM is created by the EM algorithm.

It is known that the radio wave propagation characteristics of wireless LAN change significantly in the vicinity of the base station. However, the radio wave environment is approximated by a normal distribution in the GMM, so the radio wave propagation in the vicinity of the base station cannot be reproduced perfectly. In addition, there is a drawback that it takes a lot of time to execute these programs and create a model unless a computer with high computing power is used.

Next, the estimated radio strength ($\gamma_{nAP_i}$) of the AP at the position of each particle ($a_n$) is obtained by GMM (Eq.1).

$$\gamma_{nAP_i} = GMM(a_n, AP_i)$$ (1)

From $\gamma_{nAP_i}$ and the actually measured radio strength $o_{AP_i}$, the existence probability ($p_{nAP_i}$) is obtained by the Eq.2 of the normal distribution.

$$p_{nAP_i} = \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left( -\frac{(\gamma_{nAP_i} - o_{AP_i})^2}{2\sigma^2} \right)$$ (2)

The weight $e_n$ of each particle is calculated from $p_{nAP_i}$ by Eq.3, and the normalized value of the $e_n$ is used as the weight of each particle.

$$e_n = \prod_{AP_i=1}^j p_{nAP_i}$$ (3)
5 Suggestion

On the other hand, in this research, RSSI is not used directly. In combination with the Finger Print, estimation is performed based on the distance between each particle and the Finger Print estimation result. By using the estimation result of the conventional Finger Print, it is not necessary to create a new model like the GMM, and the cost for creating the model can be suppressed. In addition, since the Finger Print estimation itself is not changed, it can be easily applied to the current system.

A large error may occur momentarily due to changes in the radio wave environment with the Finger Print singly. However, it is thought that the error can be reduced due to the influence of the estimation result of the previous time by applying the Particle Filter.

Further, it is considered that the estimation can be performed correctly even when the user is between the coordinates since the final estimation result is calculated by the weighted average of each particle.

6 Algorithms

The Particle Filter scatters point with weights called particles according to the weight (likelihood) of the previous frame. The weighted average of particles becomes the estimation result. The Particle Filter mainly consists of resampling, likelihood calculation, and estimation steps. Fig.1(a) shows a flowchart of the proposed method.

6.1 Resampling

The particles are scattered according to the weight of the previous frame. At this time, as shown in Fig.1(b), particles with low weight are eliminated, and particles with high weight are divided into multiple particles. The divided particles are scattered around the particle in the previous frame with standard deviation \( \sigma_p \) [m]. If the \( \sigma_p \) is increased, new particles will be scattered farther. On the contrary, if \( \sigma_p \) is made small, the particles will be scattered near the particles in the previous frame, so that they will be affected by the earlier time.

6.2 Likelihood calculation

As shown in Fig.1(b), the weight \( w_n \) is calculated from the distance between the coordinates estimated and each particle \( d_n \) using Eq.4. \( \sigma_w \) is standard deviation of weights.

\[
w_n = \frac{1}{\sqrt{2\pi \sigma_w^2}} \exp \left( -\frac{d_n^2}{2\sigma_w^2} \right)
\]

(4)

Normalize \( (w_n) \) with Eq. 5 and set weight \( (w_n^*) \). \( N \) is number of particles.

\[
w_n^* = w_n \times \frac{N}{\sum_{l=0}^{N-1} w_l}
\]

(5)

6.3 Estimation

The estimated position is the result of weighted averaging the positions of each particle with \( w_n^* \). Therefore, it is possible to estimate a position between the DB coordinates. Even if the user is between the coordinates, the error can be reduced. \( x \) is position of each particle and \( \bar{x} \) is estimated position.
\[ \bar{x} = \sum_{i=0}^{N} w_i^* \times x_i \]  

(6)

(a) Flowchart of proposed method

(b) Resampling and likelihood calculation

Fig. 1. Proposed method algorithm

7 Parameter design in the proposed method

In order to design each parameter of the Particle Filter, \( \sigma_p[m] \), \( \sigma_w[m] \), \( N \), we have measured under the conditions shown in Fig. 2(a), and confirmed changes in estimation accuracy as parameters.

(a) Measurement condition

|               | DB                              | UD                              |
|---------------|---------------------------------|---------------------------------|
| Place         | University of Hyogo of engineering, 6th floor, building B |                                  |
| Date and time | 2019/5/28                       | 2019/5/29                       |
| Num. of measurements | 20 times                      | 1 time                          |
| Coordinate interval | 0.5 m                         |                                  |
| Num of coordinates | 63 points                      |                                  |

(b) Num of particles changing

(c) \( \sigma_p \) changing

Fig. 2. Changes in estimation accuracy with parameters
Fig. 2(b) shows the relationship between the number of particles $N$ and the estimation error. Fig. 2(c) shows the relationship between the standard deviation of the particle scattering $\sigma_p$ and estimation error. These figures show the estimation error could be reduced by adjusting each parameter.

8 Verification

8.1 Verification condition

We compare the estimation results of the conventional MSE+APCR and the proposed method using the data measured under the conditions in Fig. 2(a). We compared the difference in accuracy between the conventional method and the proposed method when the DB coordinate interval was widened. This confirmed that the proposed method can solve the Finger Print problem described in Chapter 3. In this method, the coordinates used as the starting point of the DB coordinates are shifted and verification is performed multiple times.

8.2 Result

Fig. 3 show the results of comparing the maximum and average errors of the conventional method and the proposed method.

![Comparison of conventional method and proposed method](image)

Fig. 3. Comparison of conventional method and proposed method

It can be confirmed from Fig. 3 that the maximum error and the average error increase as the DB coordinate interval increases, and the difference between the conventional method and the proposed method also increases. From these results, it is considered that the proposed method can be expected to improve accuracy when the coordinate interval of the DB is wide.

9 Conclusion

We treated user data in Finger Print as time-series data, applied a particle filter, and confirmed the improvement of estimation accuracy by parameter design. We focused the interval of the DB coordinate, considering the measurement cost to create the DB. As a result, we confirmed that the proposed method had a smaller estimation error than the conventional method, and confirmed the effect of the proposal is increased as the DB coordinate interval became wider.