Cross-Assistive Approach for PDR and Wi-Fi Positioning

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Abstract

In indoor positioning using Wi-Fi, there is a problem that
the accuracy is not stable by the occurrence of large
errors. Large errors tend to occur when density of wireless
LAN access points is low or the radio wave condition is
unstable. Furthermore, as for positioning utilising
smartphone, it takes a while to scan Wi-Fi beacons.
Thereby, errors tend to occur while user is moving.
Because it is difficult to observe exactly Wi-Fi beacons.
Accordingly, the authors proposed Cross-Assistive
Approach for PDR and Wi-Fi Positioning. First of all,
fingerprinting that is often used Wi-Fi positioning is
improved by confining fingerprints to location where is
estimated by PDR. As a result, this approach improved
the accuracy about 2 meters. Furthermore, in order to
correct accumulated errors in PDR, the authors proposed
a method that corrects PDR with accurate Wi-Fi
positioning results. Additionally, the authors proposed a
method that estimates the accuracy of Wi-Fi positioning
results. The mean error of accurate Wi-Fi results
estimated by the accuracy estimating method was 0.98
meters. Thus, the accuracy estimating method detected
accurate Wi-Fi positioning results effectively. In the
comprehensive evaluation, our approach improved an
existing Wi-Fi method about 3.4 meters by assisted PDR
with Wi-Fi positioning and assisted Wi-Fi positioning with
PDR cooperatively. Moreover, this approach enabled

accumulated errors in PDR to be corrected.

Author Keywords
Indoor Positioning, Pedestrian Dead Reckoning, Wi-Fi

ACM Classification Keywords
K.6.4 [MANAGEMENT OF COMPUTING AND INFORMATION SYSTEMS]: System Management-Quality assurance

Introduction
Recently, location-aware services that provide information suitable for the user's situation, such as Yelp[1] and Foursquare[2], have become very popular. We usually get the location information with GPS. Nevertheless, it is difficult to estimate indoor location utilising GPS because GPS satellite waves cannot reach. Therefore, indoor positioning has been studied so that we can get the indoor location information with IMES and Wi-Fi and such [3, 4, 5]. In particular, positioning with Wi-Fi has attracted attention because it is low cost by already set wireless LAN access points. On the other hand, positioning with Wi-Fi has the problem that the accuracy is not stable by the occurrence of large errors. large errors tend to occur when density of wireless LAN access points is low or the radio wave condition is unstable. Furthermore, as for positioning utilising smartphone, it takes a while to scan Wi-Fi beacons. Thereby, errors tends to occur while user is moving. Because it is difficult to observe exactly Wi-Fi beacons.

Accordingly, we proposed the Cross-Assistive Approach for Pedestrian Dead Reckoning (PDR) and Wi-Fi Positioning. In our approach, each positioning method improves accuracy cooperatively, such as PDR improves Wi-Fi positioning and improved Wi-Fi positioning boosts PDR.

Moreover, we conducted an experiment to evaluate our approach.

Basic Indoor Positioning
There are various kinds of indoor positioning methods. This section introduces basic indoor positioning methods that are often used.

Positioning with Wi-Fi
In general, Wi-Fi positioning methods estimate the present location by beacons of the wireless LAN access point. For example, there is a method using the trilateration based on the relationship between attenuation rate of radio waves and distance between the smartphone and the wireless LAN access point, comparing RSSIs[1] learned in advance with RSSIs observed at present, estimating the present location stochastically by RSSIs observed at present, and so on.

1. **Fingerptinting**
   Bahl proposed RADAR [6] that estimates the present location by comparing RSSIs learned in advance with RSSIs observed at present. This system needs to learn the measurement coordinates and beacons of the wireless access point finely. In addition, the system clusters Wi-Fi feature values based on the measurement coordinate (fingerprint). Next, the system calculates euclidean distances between fingerprints and RSSIs observed at present. Euclidean distance is calculated as follows:

$$E_n = \sqrt{\sum_{i=1}^{m} \left(rssi_i - rssi'_i \right)^2} \qquad (1)$$

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[1]Received Signal Strength Indication

Where E is euclidean distance, n is the number of fingerprints, m is the number of common wireless LAN access points between fingerprint and Wi-Fi information observed at present, $rssi$ is RSSI observed at present, $rssi'$ is RSSI in the fingerprint. Present location is estimated by selecting the coordinate of fingerprint that has the shortest euclidean distance or calculating the coordinate by weighted average with fingerprints that have the shorter euclidean distance.

2. **Particle Filter**
   Particle filter positioning method [7] usually estimates the present location stochastically by maximum likelihood estimation method. Maximum likelihood estimation method compares radio wave environment models with RSSIs observed at present. The radio wave environment models is modeled by training Wi-Fi information in advance. Firstly, the system moves particles that are an hypothesis of the user present location. The system calculates the likelihood between the models and RSSIs observed at present in the directions of particles. Secondly, the system estimates the present location with each coordinate of particles and likelihood. One of the estimating location methods uses weighted average coordinate of the particles with weight. The likelihood is used as weight.

Pedestrian Dead Reckoning
Pedestrian Dead Reckoning (PDR) [8] is a technology that estimates a relative present location by the number of steps and the direction. PDR counts the number of steps by accelerometer sensor and estimates the direction by gyroscope sensor. Wi-Fi positioning can introduce PDR at a low cost by built-in sensors on smartphones.

Problems
This section explains problems of basic positioning methods.

Problem of positioning with Wi-Fi
Wi-Fi positioning methods have a problem that the accuracy depends of the radio wave environment of the positioning area. Figure 1 shows result of preliminary experiment using the fingerprinting. In the experiment, we walked counterclockwise from the southeast corner. The mean error was 6.7 meters because of large errors occur in the place that has open ceiling (center of Figure 1).
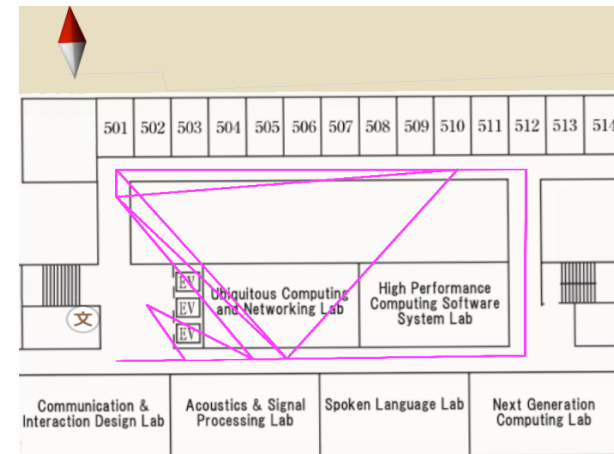

Figure 1: Trajectory of the Fingerprinting

The large errors occurrence can be caused by :

1. **Density of wireless LAN access points is low**
   The positioning area of south has many laboratories. Thus, the density of wireless access points was high. By contrast, the density of wireless

access points was low in connecting corridors of west and east. The accuracy was low in the low density place because there was no features between observed Wi-Fi information.

2. **Radio wave condition is unstable**
   A lot of packet loss was occurred in that positioning area. The packet loss occurrence was high, the positioning accuracy was lower because observing device cannot accurately observe Wi-Fi information. It is inferred that a packet loss tends to occur in unstable radio wave environment, such as reflection or interference is strong.

3. **Users walk around during observation**
   The Wi-Fi positioning with a smartphone takes more than two seconds to scan Wi-Fi beacons. Even if smartphone scan Wi-Fi beacons with two seconds interval, the distance walked in that time is large. Therefore, large errors occur because the smartphone cannot scan Wi-Fi beacons.

Thus, positioning methods with Wi-Fi have limitations depending on situations. Additionally, existing Wi-Fi positioning methods cannot know accuracy, so applications can only use results as it is. Consequently, bad positioning results have a bad impact on applications.

Problem of PDR
PDR estimates a present location at a tidy trajectory. On the other hand, PDR has a problem that accuracy decline by accumulating sensing errors. Additionally, it is difficult for PDR to correct accumulated errors because PDR estimates the present location relatively.

Cross-Assistive Approach for PDR and Wi-Fi Positioning

In order to enable high accuracy Wi-Fi positioning in situations that have the accuracy limitation, we proposed Cross-Assistive Approach for PDR and Wi-Fi Positioning (Figure 2). In our approach, each positioning method improves accuracy cooperatively, such as ① PDR improves Wi-Fi positioning and ② improved Wi-Fi positioning boosts PDR. Accordingly, we established above two methods, and we created a cooperative mechanism.
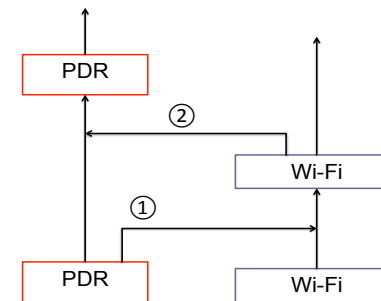

Figure 2: Cross-Assistive Approach for PDR and Wi-Fi Positioning

Assisted Wi-Fi positioning with PDR
Firstly, we considered the method ① PDR improves Wi-Fi positioning. We used fingerprinting that is commonly used in the Wi-Fi positioning. The fingerprinting used the estimation method selecting coordinate of fingerprint that has the shortest euclidean distance. Fingerprints are measured in each positioning area such as floors of building, underground mall and so on. Additionally, if positioning area becomes bigger, the range of fingerprint matching during positioning is widened. Thus, large errors become easy to occur due to being selected fingerprint apart from the present location when a calibration device

cannot receive Wi-Fi beacons accurately. Therefore, we proposed a method that sets a limit to matching fingerprints during positioning. Firstly, PDR estimates the present location. Secondly, fingerprinting selects fingerprints close to the present location estimated by PDR. Thereby, the limitation of the fingerprints prevents large errors occur even when Wi-Fi beacons cannot be received accurately.

Assisted PDR with Wi-Fi positioning
Secondly, we considered the method ② Wi-Fi positioning boosts PDR. This method corrects the present location and the direction of PDR by accurate Wi-Fi positioning results. Therefore, it is necessary to determine if Wi-Fi positioning result is accurate, and determine Wi-Fi positioning accuracy with a property that PDR results become a consecutive trajectory. We defined what an accurate Wi-Fi positioning result is :

$$dist_w \leq dist_p \qquad (2)$$
$$dir_p - \alpha \leq dir_w \leq dir_p + \alpha \qquad (3)$$

Where, $dist_w$ is the distance of Wi-Fi positioning results, $dist_p$ is the distance of the PDR result, dir_w is the direction of Wi-Fi positioning results, dir_p is the direction of the PDR result, α is any angle. Firstly, PDR estimates the present location using the number of steps and the step length that is set in advance. Secondly, the estimating accuracy method calculates distance between latest Wi-Fi positioning result and latest accurate Wi-Fi positioning result. If there is no accurate Wi-Fi positioning result, the method calculates distance between latest positioning result and one result before latest result. In consequence, if $dist_w$ is shorter than $dist_p$, it is presumably that the Wi-Fi positioning result is accurate because of fitting (Equation 2). On the other hand, dir_w is unstable, and it is not always true that dir_w is similar

to present user direction. Therefore, the method adopt only a Wi-Fi positioning result that transited within α degree from PDR direction (Equation 3). The method estimates that Wi-Fi positioning result is accurate when two conditions are met. Owing to it, the estimating accuracy method can remove Wi-Fi positioning results in which transition distance is short and transition direction different from present user direction. Additionally, the method corrects accumulating errors simply by assigning the coordination of the Wi-Fi positioning result to the coordination of a criterion in PDR and the direction of the Wi-Fi positioning result to the direction of a criterion in PDR.

Cross-Assistive Approach
Finally, above described approaches improve integrated accuracy cooperatively by repeating the following process:

1. Improve fingerprinting accuracy by PDR

2. Estimate whether a fingerprinting result is accurate

3. Correct accumulating errors of PDR by the accurate fingerprinting result

Thus, our approach can remove large errors in Wi-Fi positioning, and correct accumulating errors of PDR.

Evaluation
In this section, we evaluated proposed methods.

Results improving fingerprinting using PDR
Firstly, we measured Wi-Fi information and set fingerprints showed as red pins in Figure 3. Additionally, the fingerprinting uses estimation method selecting coordinate of fingerprint that has the shortest euclidean distance. In the experiment, we walked at a constant

speed counterclockwise from the southeast corner in the floor. The floor size is about 40 m × 20 m. Moreover, we calculated answer coordinates from walking time and walking distance. We set default values of PDR such as the coordinate and the direction in advance.
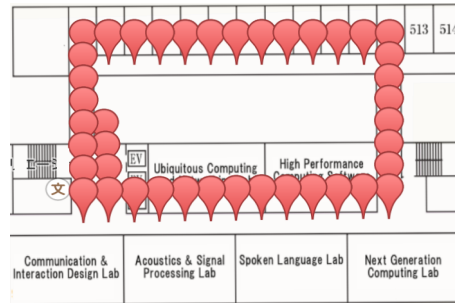

Figure 3: Set Fingerprints

Figure 4 shows results of experiment using improved fingerprinting. Actual positioning results have spread on corridors, and there are overlaps in the trajectory. Comparing Figure 1 and Figure 4, positioning results with proposed method similar to measurement route, and Figure 4 has no large errors. Additionally, Table 1 shows mean errors of existing method and proposed method. As a result, proposed method improved accuracy about 2 meters. Nevertheless, as shown in Figure 5, the accuracy became lower over time in this approach. It is inferred that the approach could not limit fingerprints properly because the accuracy of PDR became lower by accumulated errors.
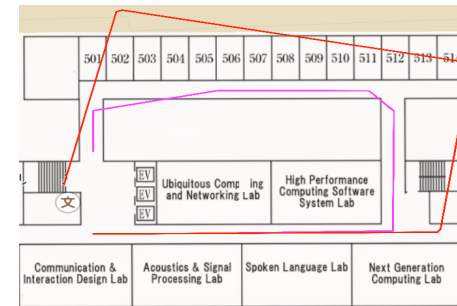
Wi-Fi with PDR: inner rectangular trajectory (purple)

PDR: outer rectangular trajectory (red)

Figure 4: Trajectory of the Fingerprinting

Table 1: Mean Error of the Fingerprinting

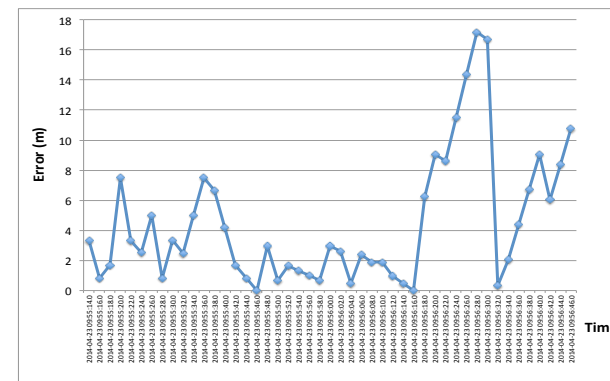|	Wi-Fi	Wi-Fi with PDR
Mean error (m)	6.73	4.47

Figure 5: Errors of the Fingerprinting

*Results considering method for estimate Wi-Fi positioning accuracy*

We verified the precision of accurate Wi-Fi positioning results estimated by the Wi-Fi accuracy estimating method with PDR. Table 2 shows a mean error of accurate results that were estimated by the estimating method. As a result, the precision of estimation was high, hence the proposed method estimate the accuracy of Wi-Fi positioning effectively.

Table 2: Mean Error of Accurate Results Estimated by Proposed Method

	method for estimate the accuracy
Mean error (m)	0.982

Cross-assistive approach

Finally, we evaluated a integration positioning. We used described above settings. Figure 6 shows trajectories of PDR, Wi-Fi with PDR and cross-assistive approach. As a result, cross-assistive approach could correct trajectory by fixing incorrect PDR results such as passing a corner. On the other hand, as shown in Table 3, cross-assistive approach could improve the accuracy 3.4 meters more than existing method.
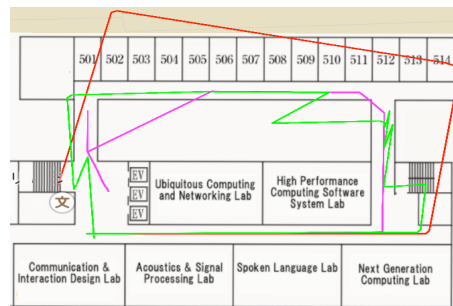
Wi-Fi with PDR: Inner rectangular trajectory (purple)

Cross-Assistive Approach: Medium rectangular trajectory (green)

PDR: Outer rectangular trajectory (red)

Figure 6: Trajectory of the Cross-Assistive Approach

Table 3: Average Error of each Positioning Method

	Wi-Fi	Wi-Fi with PDR	Cross-Assistive Approach
Mean error (m)	6.73	4.47	3.31

Related Work

This section introduces related works such as improving fingerprinting, developing integration positioning using dead reckoning and Wi-Fi.

Improved fingerprinting with Bluetooth

Baniukevic improves fingerprinting with Bluetooth [9]. This approach divides a positioning area optimally by setting Bluetooth base stations that send Bluetooth beacons. Firstly, they set Bluetooth base stations based on positioning error measured in advance and the number of fingerprints , and divide optimally positioning area that fingerprints are set. Additionally, this approach do not divide fingerprints at the similarity of Wi-Fi feature value into same positioning area because of positioning error is easy to occur. They define hotspot as places that Bluetooth base station is set. This approach improves positioning accuracy by hotspot to divide fingerprints area. In the evaluation, they set two Bluetooth base stations in a floor that has an area of 50 m^2. As a result, this approach improved a positioning mean error from 9.75 meters to 7.57 meters. Although this approach improves a positioning accuracy, this approach has problems such as setting of Bluetooth base stations takes a cost, it is necessary to calculate positions that

Bluetooth base stations are set.

Advanced Integration of Wi-Fi and Inertial Navigation Systems

Evennou proposes the integration positioning with Wi-Fi and dead reckoning framework [10]. The proposed method fuses dead reckoning framework that uses inertial navigation sensors, such as accelerometer, gyroscope and pressure sensor, into particle filter positioning. Firstly, this approach prevents particle filter positioning from calculating results including irremovable coordinate by map information. Actually, likelihoods of the particle that moved in the wall is set 0. Additionally, this approach improves a positioning accuracy by spreading particles following PDR around actual present location. This approach has problems because it is necessary to prepare map in advance , the calculation volume is large due to using a lot of particles, and so no.

Although there are approaches that improve existing Wi-Fi positioning methods, they cannot estimate a Wi-Fi positioning accuracy in real time.

Conclusion

In order to enable high accuracy Wi-Fi positioning in the situation that has accuracy limitations, we proposed Cross-Assistive Approach for PDR and Wi-Fi Positioning. First of all, we improved fingerprinting by confining fingerprints to a location where is estimated by PDR. As a result, we improved the accuracy about 2 meters. Furthermore, in order to correct accumulated errors in PDR, we proposed a method that corrects PDR with accurate Wi-Fi positioning results. The mean error of accurate Wi-Fi results estimated by the accuracy estimating method was 0.98 meters. Thus, the accuracy estimating method detected accurate Wi-Fi positioning

results effectively. In the comprehensive evaluation, our approach improved an existing Wi-Fi method about 3.4 meters by assisted PDR with Wi-Fi positioning and assisted Wi-Fi positioning with PDR cooperatively. Moreover our approach enabled accumulated errors in PDR to be corrected. Additionally, we improve estimating Wi-Fi accuracy method by considering situation of stay and not using PDR as a future work. Moreover, we consider algorithms to correct complex trajectories such as meandering.

Acknowledgements

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