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Integration of Pedestrian DR and Beacon-AP based Location System for Indoor Navigation

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ABSTRACT

Though the global navigation satellite systems (GNSS) are widely used in various location based services (LBS), it can hardly be used indoors due to signal blocking or multipath fading. For indoor LBS, various location systems have been developed and examples include WiFi multilateration, RF fingerprint, UWB WPAN, and pedestrian dead reckoning (PDR). Owing to rapid deployment of the smartphone, WiFi location systems and PDR are more highlighted as a candidate of indoor location solution recently.
Because WiFi multilateration utilized received signal strength indicator (RSSI) measurement in ranging, its positioning accuracy is somewhat poor. Though the performance of RF fingerprint is better than that of WiFi multilateration, its performance is sensitive to RF environment. Moreover, if many access points (AP) are installed to improve their location performance, interference between APs becomes critical in data communication.
In the PDR, pedometer is commonly used to measure distance and the heading direction is found using magnetometer and/or gyroscope. Because dead reckoning (DR) sensor errors are accumulated in the computation, location error of PDR increases cumulatively as time goes if the position and heading are not calibrated properly.
This paper presents a novel indoor navigation system integrating beacon-type AP and PDR. To minimize the interference and to find user position with high accuracy, we developed a beacon-type AP that has a small footprint. When the beacon-type APs are installed at the crossroad and the

footprint of each AP covers each direction of corridor, smartphone users can easily obtain their precise position and moving direction. Because beacon-type AP has a small footprint, PDR is used to compute user position between the footprint coverage of beacon-type AP. Comparing the AP position and the output of PDR, user position and heading are calibrated. Moreover, pedometer scale factor and gyro bias are estimated to improve the performance of PDR. By field experiments, performance of the proposed indoor navigation system will be verified.

KEYWORDS: Pedestrian DR, Beacon-type AP, Indoor navigation

1. INTRODUCTION

In accordance with explosive growth of the smartphone market, the needs to get the user position using the smartphone increases. Many researches are performed to localize the user position by using the smartphone. For the outdoor positioning, global positioning system (GPS) is utilized. On the other hands, Pedestrian DR (PDR) and WiFi based positioning is available using smartphone for the indoor localization. DR sensors such as the accelerometer, the gyroscope, and the magnetometer are exploited for the pedestrian DR. And the received signal strength (RSS) of WiFi signal is used to calculate the user position.

Pedestrian DR detects steps and updates the user position when a step event has occurred. By using PDR only, there is no means of correcting the heading and the user position as well as calibrating PDR otherwise navigation aids should be augmented.

There are two fundamental methods of the positioning that uses RSS. The former utilizes the known radio analytic formula. And the latter uses the pre-measured database, which is often referred as fingerprinting. Since the free space pass loss model is vulnerable to non-line of sight (NLOS) signal which leads to tens of meters error, fingerprinting-based positioning methods are developed. To increase positioning accuracy with fingerprinting, more APs are needed which leads to more interference between APs. To solve this problem, beacon-AP generates only meters of small footprint of the WiFi signal.

On the other hand, the coverage of beacon-AP would be in ten meters and to cover a building, many APs are needed. In the corridor type building, a few beacon-AP can cover whole floor interpolating with PDR. By integrating PDR and beacon-AP positioning results, not only the stride length but also the heading and the position of the user can be corrected. In this paper, the integration scheme of PDR and beacon-AP is proposed. To begin with, the PDR error model is concerned and the measurement model is described in order to build the integrated filter. Experimental results show that the integrated filter shows better accuracy than PDR only.

2. THE PEDESTRIAN DR AND BEACON-AP INTEGRATED FILTER

Users can acquire their position in accuracy of three to five meters by using beacon-AP. By using a directional antenna, beacon-AP could fulfil small footprint. If the received signal is over the predetermined threshold value, the position can be calculated with relatively high accuracy than the fingerprint method without interference between APs. Figure 1 shows the concept of that system. However, users are unable to localize between beacon-APs out of coverage otherwise many beacon-APs are needed to cover the area.

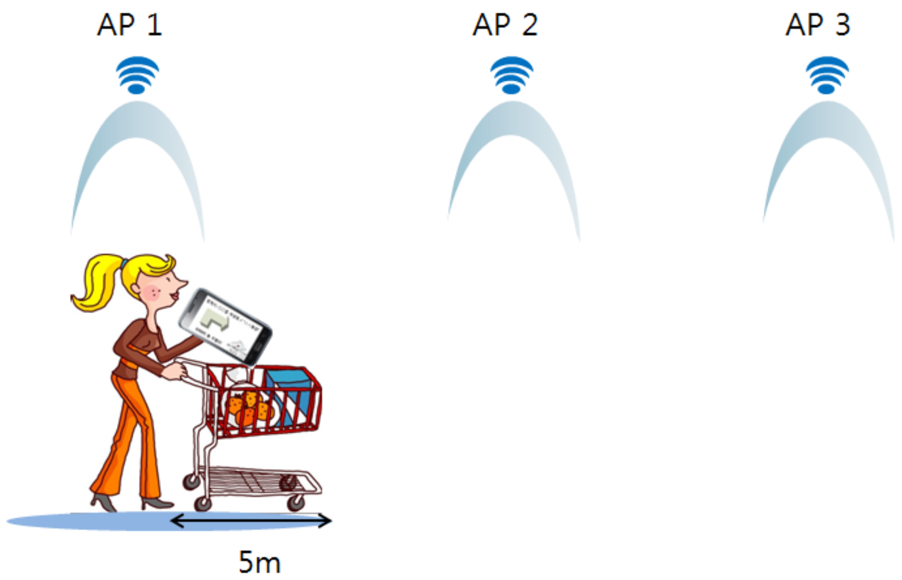

Figure 1. The concept of the beacon AP based indoor navigation system

Performing pedestrian DR using smartphone sensors only leads to the cumulative position error. Integrating beacon-AP and smartphone sensors, the user can get the position with accuracy and continuity between beacon-APs. To integrate PDR and Beacon-AP, PDR/AP integration filter should be designed. The heading error, the gyro scale factor error, and the pedometer scale factor should be estimated and fed back to correct the user's position.

2.1 Error Model

To implement PDR/AP integrated filter, the error model of pedestrian DR is required. To build the error model, error factors of the PDR such as the heading error, the gyro bias error, and the pedometer scale factor error are examined.

a. The Pedometer Scale Factor Error

The pedometer scale factor represents the difference between the nominal stride length and the actual step length. The nominal stride length is usually set to be 800 millimeters. In this paper, 700 millimeters is assumed by considering different nations. Indeed, some paper deals with the stride length estimation, which is different from persons and characteristics of gaits. Furthermore, as the noise in the PDR is cumulatively increases, it is hard to deal with without any information.

b. The Gyro bias

The gyro sensor calculates the rotation of the equipment by integrating angular velocity. On the other hands, the gyro output contains the bias error which is the average output when the gyro is sitting still, and this value is not zero. By accumulating the gyro output, gyro bias causes linearly increase error. If there is no proper handle, the system calculates its attitude in the false direction.

c. The Heading error

The heading error is the error between virtual heading and calculated heading using the gyroscope output. It is related to the gyro bias error and the random walk. By summarizing, the Pedestrian DR error model is written as

$$\begin{bmatrix} \delta\psi(k+1) \\ \delta b_G(k+1) \\ \delta Sf_{pedo}(k+1) \end{bmatrix} = \begin{bmatrix} 1 & \Delta t & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \delta\psi(k) \\ \delta b_G(k) \\ \delta Sf_{pedo}(k) \end{bmatrix} + \begin{bmatrix} w_\psi(k) \\ w_{b_G}(k) \\ w_{Sf_{pedo}}(k) \end{bmatrix} \qquad \text{eq. (1)}$$

where $\delta\psi(k)$ is the heading error, $\delta b_G(k)$ is the gyro bias error, and $\delta Sf_{pedo}(k)$ is the pedometer scale factor error. $w_\psi(k)$, $w_{b_G}(k)$, and $w_{Sf_{pedo}}(k)$ represents the noise in the heading, the gyro bias, and the pedometer scale factor respectively. The positioning error model by using error factors in the error model can be represented as

$$\begin{bmatrix} \delta P_E(k+1) \\ \delta P_N(k+1) \end{bmatrix} = \begin{bmatrix} \delta P_E(k) \\ \delta P_N(k) \end{bmatrix} + \begin{bmatrix} s(k)\cdot\cos\psi(k) & s(k)\cdot\dfrac{\sin\psi(k)}{Sf_{pedo}(k)} \\ -s(k)\cdot\sin\psi(k) & s(k)\cdot\dfrac{\cos\psi(k)}{Sf_{pedo}(k)} \end{bmatrix} \begin{bmatrix} \delta\psi(k) \\ \delta Sf_{pedo}(k) \end{bmatrix} + \begin{bmatrix} w_{P_E}(k) \\ w_{P_N}(k) \end{bmatrix} \qquad \text{eq. (2)}$$

where $\delta P_N(k)$ is the position error in the north direction, $\delta P_E(k)$ is the position error in the east direction, and $s(k)$ is the moving distance. $w_{P_E}(k)$ and $w_{P_N}(k)$ represents the positioning noise for each direction.

2.2 Measurement Model

The measurement model in the integrated PDR / Beacon AP is represents as the difference between PDR based and beacon-AP based displacements, which is written as

$$\begin{aligned} \delta z &= \begin{bmatrix} \delta P_{E,PDR}(k) - \delta P_{E,AP}(k) \\ \delta P_{N,PDR}(k) - \delta P_{N,AP}(k) \end{bmatrix} \\ &= \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \delta P_E(k) \\ \delta P_N(k) \\ \delta\psi(k) \\ \delta b_G(k) \\ \delta Sf_{pedo}(k) \end{bmatrix} + v(k) \\ &\equiv H \cdot \delta x + v(k) \end{aligned} \qquad \text{eq. (3)}$$

where the measurement noise $v(k)$ is assumed to be a white Gaussian, and the covariance matrix $R(k) = \mathrm{cov}[v(k)]$.

2.3 The Implement of Pedestrian DR / Beacon-AP Integration Filter

By using the PDR/AP integration filter, users can correct their heading and position and calibrate their stride length. Figure 2 show this scheme.

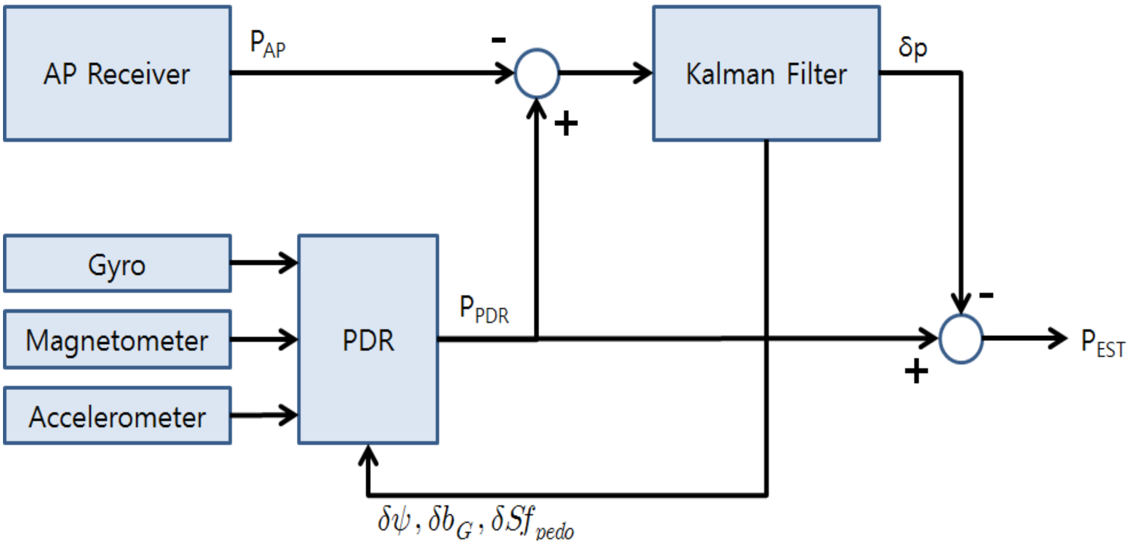

Figure 2. Kalman Filter-based Pedestrian DR / Beacon AP integration filter

To integrate measurements, Joseph form Kalman filter is used. Joseph form maintains symmetricity of the error covariance matrix P and hence positive definiteness although this form of the Kalman filter is sub-optimal.

$$
\begin{aligned}
P_k^- &= \Phi_{k-1} \cdot P_{k-1}^+ \cdot \Phi_{k-1}^T + Q \\
K_k &= P_k^- \cdot H_k^T \cdot \left[H_k \cdot P_k^- \cdot H_k^T + R\right]^{-1} \\
\delta\hat{x}_k &= K_k \cdot \delta z \\
P_k^+ &= \left[I - K_k \cdot H_k\right] \cdot P_k^- \cdot \left[I - K_k \cdot H_k\right]^T + \Phi_{k-1}^T + K_k \cdot R \cdot K_k^T
\end{aligned}
\qquad \text{eq. (4)}
$$

3. EXPERIMENTAL RESULTS

To verify the integrated filter designed in this paper, some experience is conducted. The corridor type building is selected for this purpose. Five beacon-APs are installed in accordance with the corridor.

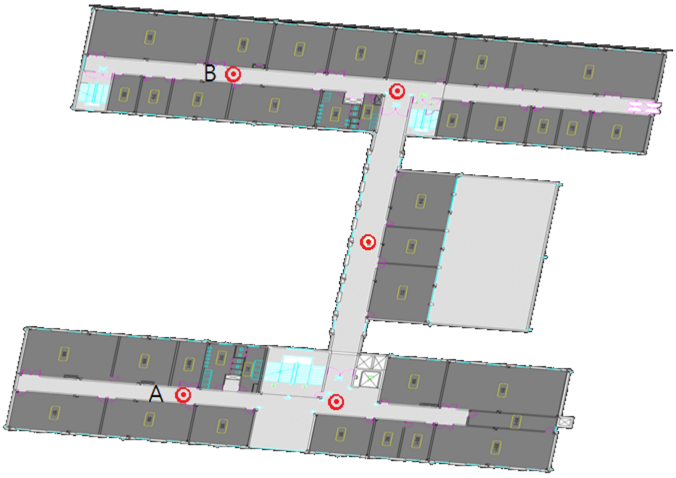

Figure 3. Field description (corride type)

Using the smartphone (Samsung galaxy tab 10.1), sensor data such as the accelerometer, the gyroscope, and the magnetometer and RSS of beacon-AP is logged. The experiment is conducted point A to B back and forth. This system detects AP to be sensed if RSS of the smartphone exceeds predefined threshold. By increasing threshold, the accuracy of beacon-AP based position increases. However, this also causes the misdetection of beacon-AP. Pedestrian DR only navigation is shown in figure 4.

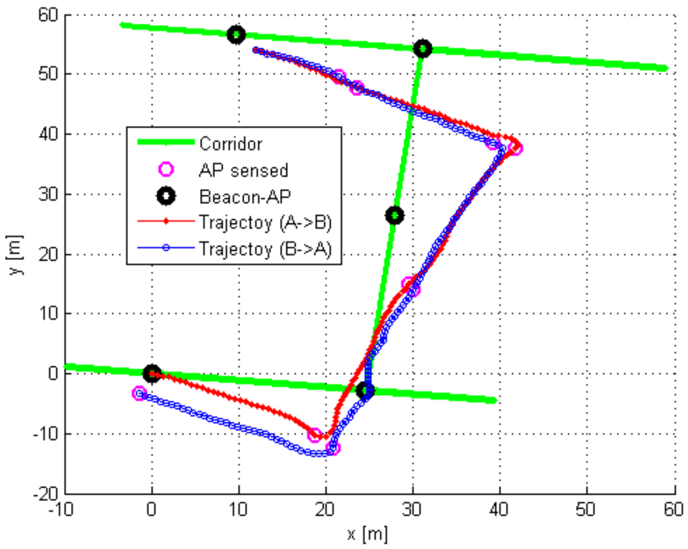

Figure 4. The result of PDR only

The PDR only result show that the heading of navigation data is inclined since there is no mean to check the user’s heading. Although the magnetometer is used together, the magnetic interference causes the heading error especially in the indoor environment. By integrating beacon-AP based position with PDR, error factors in PDR can be compensated. Figure 5 shows navigation result of proposed integration filter.

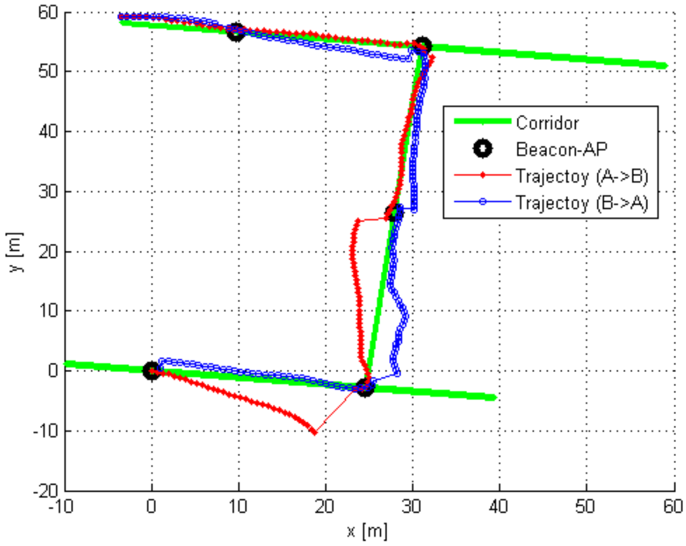

Figure 5. The result of PDR/AP integrated filter

The result shows that PDR/AP integrated filter can correct the heading error and the pedometer scale factor.

4. CONCLUSIONS

In this paper, PDR/AP integration filter is designed and verified. First of all, the error model of PDR is analysed and the measurement model of PDR/AP integration filter is followed. Experimental result shows that PDR/AP integration filter shows better accuracy over PDR only solution due to compensating the heading error, the position error and the pedometer scale factor error. Further study has to be made to analyse the positioning error and minimize this error using algorithms such as the map-matching algorithm.

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