Indoor Positioning System with IMU, Map Matching and Particle Filter

Nammoon Kim, Youngok Kim*
Department of Electronic Engineering
Kwangwoon University
26 Kwangwoon-gil, Nowon-Gu, Seoul, 139-701
South Korea
knm123@kw.ac.kr, kimyoungok@kw.ac.kr

Abstract: - Position information of pedestrian is nowadays very important in many applications. Global Navigation Satellite System is not suitable for indoor navigation because of signal strength attenuation and multipath effects. The positioning techniques based on wireless radio signal, such as Wireless Local Area Network, require additional infrastructure that cannot be used freely. We propose a novel position estimation scheme exploiting a smartphone with inertial measurement unit (IMU). In the proposed scheme, step detection, step distance estimation and orientation are estimated by using inertial sensors of smartphone. Map Matching and particle filter techniques are applied to improve performance of positioning. The proposed scheme has improved the performance of about 60% than the conventional scheme.

Key-Words: Indoor Positioning, inertial sensor, map matching, particle filter, pedestrian dead reckoning (PDR)

1 Introduction

The importance of the Location Based Services (LBS) is growing with the development of various industries utilizing the information of individual location and the increase of the smartphone users. However, the usage of the Global Navigation Satellite System (GNSS) is very limited in indoor environments and the position accuracy of GNSS can be very poor in urban canyons consisting of a high rise building. To overcome this disadvantage, various methods and techniques have been proposed, such as, Wireless Local Area Network(WLAN), Bluetooth, Ultra-wideband (UWB), Visible Light Communication (VLC), and Pedestrian Dead Reckoning(PDR) and so on [1]. WLAN have been used for indoor positioning in various places. For WLAN based positioning, several methods are known, such as radio signal strength with wireless signal propagation model, triangulation and fingerprinting. The fingerprinting method is the most used method in various fields. This scheme requires a database of offline collected measurements of the signal strengths from the reference points. On online phase, the measured signal strength at the user’s location is compared against the database and the position is estimated according to that [2]. Much time is consumed to generate database for reference position. Also, Database is regenerated according to the environment change. The positioning accuracy is proportional to density of reference point [3]. Even though WLAN is installed in many places, but it is difficult to obtain a high accuracy because WLAN devices are installed for communication purpose without consideration of the positioning. UWB is another wireless technology for indoor positioning. UWB estimates the position of users in the close range by using the transmitted and received extremely short pulses of a sub-nanosecond. There are some methods for estimation of users such as Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA). The characteristic of the signal is used to overcome the multipath problem of the radio signal based positioning technology. In addition, the impact of the obstacle is less than other wireless technology because of UWB uses wide frequency band. However, to apply in a large space and building is not suitable because the high cost and the short range technology. Another technology also requires additional infrastructure and database construction through the data collection. Sensor technology has been developed with development of the Micro Electro Mechanical System (MEMS) technology, which results in downsizing and performance improvement of sensors. Various sensor based positioning technologies have been introduced with the development of sensor technology. The benefit of MEMS sensors compared with other technologies is significantly smaller size and low price, and many utilization rate through the smartphone, which makes them attractive. In addition, the advantage of this technique is that a sensor based techniques can be used without restrictions of other infrastructure. The navigation system based on Inertial
Measurement Unit (IMU) is one solution to overcome previously mentioned problem of various positioning techniques. Pedestrian Dead Reckoning (PDR) technique estimates the current position of a pedestrian in relation to known initial position based on inertial sensor [4]. The PDR does not need additional infrastructure and can be operated by a stand-alone device like a smart-phone because of its inertial sensors. Both step detection and orientation estimation are the cores of the PDR scheme. In addition, step distance estimation scheme of pedestrian is another important technique for enhancing the estimation accuracy. In this paper, we propose a novel position estimation scheme exploiting a smartphone with inertial measurement unit (IMU) for an enhanced Indoor Navigation System (INS). In the proposed scheme, link and node based Map Matching (MM) and Particle Filter (PF) also are applied to improve system performance. The proposed schemes are evaluated with the conventional positioning scheme without MM and PF through experiments in indoor environments. This paper is organized as follows. Section 2 provides the Structure of the proposed system. Section 3 describes the proposed positioning algorithm in detail. Section 4 provides the experiment results of proposed scheme with conventional scheme. Finally, the conclusion and future works are given in section 5.

2 Structure of the proposed system

Fig.1 shows the proposed scheme for position estimation of a pedestrian. Sensor data is collected from accelerometer, geomagnetic, gyroscope sensors in smartphone. Low pass Filter (LPF) is used to make the typical repeating waveform more observable. Rotation matrix is obtained from accelerometer and geomagnetic sensor data for transforming the coordinate of data from device coordinate to world coordinate. The sample data for step detection is obtained from rotation matrix and accelerometer data. The step of a pedestrian is detected through the step detection algorithm. The orientation of pedestrian is estimated through the integration of the angular velocity that is obtained from gyroscope sensor. The estimated position of the pedestrian with the detected step and the estimated orientation is corrected by using the MM and PF. Finally, the position of the pedestrian is estimated with the combined scheme.

3 Proposed positioning algorithm

Fig. 1 shows the proposed scheme for position estimation of pedestrian. The proposed positioning algorithm is described in detail in this section.

3.1 Traveled distance estimation

Traveled distance estimation is divided two parts: step detection and actual step length estimation. The traveled distance is obtained through step counting. In this paper, step counting is performed in real-time with 3-axis accelerometer data. Rotation matrix is applied to remove noise components generated from the different actions against the step motion. Rotation matrix can be expressed as follows:

$$
R = \begin{bmatrix}
c\theta c\psi & s\theta c\psi & -c\phi s\theta - c\phi s\psi \\
-c\theta s\phi & c\theta c\phi + s\phi s\psi & c\phi s\theta \\
-s\phi c\theta & s\phi s\theta & c\phi c\theta
\end{bmatrix}
$$

where, c and s is cos and sin. $\theta$, $\phi$, and $\psi$ represent three rotation angles of x, y and z axis. The accelerometer sensor data is converted from device frame to world frame through multiplication of the rotation matrix and accelerometer sensor data, i.e. $X = \text{Acc} \times R$. $X$ is composed of 3-vector values. The sample data for step detection is sum of $X$, i.e. sample data = $X_x+X_y+X_z$. In addition, time threshold and peak threshold are applied to improve step detection accuracy. Time threshold is applied to solve the repeatedly detected problem because of noise. The detected step in less than a threshold time from previous step is ignored. Peak threshold can remove sensor noise. The sample data is changed on the basis of 0 by removing the gravity value from sample data.
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<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>D</th>
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<td>0.01</td>
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<td>1816</td>
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<tr>
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<td>0.05</td>
<td>0.05</td>
<td>6.03</td>
<td>6.90</td>
<td>6.91</td>
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**Table 1** Analysis result of experiment results

3.1.1 Step distance estimation

The step distance of a pedestrian is always changed. Therefore, applying fixed step distance causes a performance degradation. For solving this problem, in this paper, height, average step distance and frequency, amplitude and period are compared and analyzed. There are methods using the frequency characteristics like Short Time Fourier Transform (STFT) for step distance estimation of pedestrian [5]. However, many battery consumption and delay may be occurred due to the high computational complexity. That is a big problem in the case of a small hand-held device that has a small battery. Therefore, we consider only the time domain.

Fig. 2 shows the relation between step distance and height of pedestrian and amplitude, frequency and step period. The first-order linear equation is obtained using curve fitting toolbox of Matlab tool. The Sum of Squares due to Error (SSE) and Root Mean Square Error (RMSE) were obtained through an analysis of the relationship of each feature. Table 1 is an analysis result. From this analysis result, the relationship between the amplitude of sample data and step distance is higher than relation of another features. The estimated first-order linear equation of amplitude and step distance is shown in Fig. 3, and the linear equation is \( y = 0.03781 \times X + 0.5671 \).

3.1.2 Orientation estimation

The orientation estimation is one of the important part of the PDR. In many researches, the orientation estimation schemes based on geomagnetic sensor have been studied [6]. However, high reliability orientation cannot be estimated because of the impact of building structures and influence of the peripherals in indoor environment. For this reason, in this paper, orientation is estimated using gyroscope sensor. It can solve the orientation errors that occur due to the influence of the peripheral magnetic field. However, in the gyroscope sensor based orientation estimation, the initial orientation is important because gyroscope sensor based orientation can be obtained relative orientation.

Figure 2 Relation between step distance and height of pedestrian and amplitude, frequency and period

Figure 3 First-order linear equation between amplitude and step distance
In this paper, the initial orientation was set to pedestrian, and the problem with the initial orientation was solved through a combination of various techniques, which have not been described in detail because it is beyond the scope of this paper. Angle of changed orientation during sampling time can be obtained through the integration of the angular velocity. It is possible to estimate the current orientation of a pedestrian by the accumulation of the changed angle from the initial orientation. Even though the accuracy of the orientation is high in short traveled distance, the cumulative error is increased with the increase of the traveled distance. MM algorithm has been applied to solve this problem.

3.1.3 Map Matching algorithm
The technique of sensor base navigation has a limit of performance because the intrinsic error of the sensor and accumulation error can be caused by action of pedestrian. The MM is applied for complementing. Link-node method that is a one of the most widely used technology in the map matching techniques is applied. In addition, the movement of pedestrian available space was enlarged by adding information of the corridor width to solve the disadvantages, which is that a pedestrian only located above link. Fig. 4 shows link, node, and allowed move passages in the experiment environment.

The estimated position of the pedestrian is deviate from movable area because of the cumulative error in the stride distance and orientation estimation. There are two problems resulting from the accumulated error: a leaving the straight moving and a leaving due to turning-point error. These two problems can be solved based on the map information. The problem of a leaving the straight moving can be solved the problem through the rotation correction. The position of the pedestrian always contains a link that is composed of the start and end nodes. If a pedestrian is located outside the allowed movable areas during straight moving, the angle between the located link and the current

Figure 4 Node, link and allowed move passages for Map Matching

Figure 5 Position correction method using map information
position can calculate the opposite node in the moving orientation of the pedestrian as a reference point. Position of the pedestrian is corrected over the closed link by the rotation of the obtained angle. The problem of a leaving the straight moving can be solved. A leaving due to turning-point error is that the error occurred because of the early or late rotation than the real turning point by estimation error of traveled distance. In this case, the rotation of the pedestrian can be estimated that the pedestrian was rotated based on node in the moving orientation of located link. The position of pedestrian after rotation is corrected through the estimated rotation node and compensation for distance after rotation. Fig. 6 shows the position correction method using map information.

3.1.4 Particle Filter

The particle filter is one of the prediction technique of continuous Monte-Carlo method and it has been applied to improve the position estimation accuracy. The position of the pedestrian is determined by generated particles having different weight. The position estimation method using a particle is as follows:

1. N number of particles are generated at the start point of the pedestrian with 1/N weight.
   
   $$P_0 = U_o + N(0, \alpha_0), \quad P_w = \frac{1}{N}$$  \hspace{1cm} (2)

2. If the pedestrian is moving, the particles are moving according to estimated step distance and orientation with a different random Gaussian noise.
   
   $$P_k = P_{k-1} + D \times \begin{bmatrix} \sin(\theta) \\ \cos(\theta) \end{bmatrix} + N(0, \alpha_p)$$  \hspace{1cm} (3)

3. The weight of the moving particles is updated based on the distance between link and particle position and the area of the particle.
   
   $$p^i_w = p^i_w \times f(x = d_{lp})$$  \hspace{1cm} (4)

   $$p^i_w = 0 \quad \text{(if } d_{lp} > d_c)$$  \hspace{1cm} (5)

4. The particles in the non-moving areas are regenerated the position of the particle with the highest weight.

5. If the sum of the total particle weight lower than a reference value of valid particle, total particles are regenerated at the current position of the pedestrian with 1/N weight.
   
   $$N_{th} > N_{eff} = \frac{1}{\sum_{i=1}^{N}(p^i_w)^2}$$  \hspace{1cm} (6)

6. The position of the pedestrian is estimated according to the position and weight of particles. Repeat execute from step 2.
   
   $$U_k = \sum_{i=1}^{N} p^i_k \cdot p^i_w$$  \hspace{1cm} (7)

Fig.7. Shows block diagram of particle filter

where, $U_0$ and $P_0$ are the initial position of the pedestrian and particles. $U_k$ and $P_k$ are the k-th position of the pedestrian and particles.$p^i_w$ is weight of i-th particle. N, D, and $\theta$ are the number of generated particle, estimated step distance, and orientation difference between current orientation and initial orientation. $N_{th}$ and $N_{eff}$ are reference value to maintain the number of effective particles and the number of effective particles. $d_{lp}$ and $d_c$ are the distance between particle and link and corridor width. $F(x)$ is random Gaussian distribution function.

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![Figure 6 Block diagram of particle filter](image-url)
4 Experiment results

For performance evaluation of the proposed scheme, the experiments were conducted in indoor environments. We used a smart-phone SHV-E330K and Android 4.1 KitKat with inertial sensors of smart-phone. The experiment was verified through the development of an android application. The experiment was performed in a state of being fixed to the hand assuming a deliberate condition likewise for the navigation purpose. The sampling time of sensor data is 10Hz. LPF parameter is 0.6. The threshold of time and amplitude are 300ms and ± 0.2. N is 100. $N_{th} = 0.02$. The total movement of the experiment is about 176m. The experiment was repeated with 10 trials.

Fig. 6 shows experiment results of proposed scheme in indoor environment. Blue circles represent the estimation position based on orientation estimation method with gyroscope sensor and correction method through rotation detection. Red circles shows the results of the proposed method in this paper. Performance evaluation results of the experiments are given in Table 2.

The average error of the proposed scheme is 4.19m, and the average error of the conventional scheme without MM and PF is 10.71m. The proposed scheme has improved the performance of about 6.5m by improving the performance about 60% than comparative technique.
Table 2 Experiment results in indoor environment of proposed system (10 trials)

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<td>Gyro based Orientation estimation and Corner detection</td>
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<td>Error(m)</td>
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<td>Gyro based Orientation estimation, Map Matching and Particle filter</td>
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<td>Error(m)</td>
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<td>5.70</td>
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</table>

5 Conclusions and future works

This paper proposed an indoor positioning system based on step length estimation, gyro based orientation estimation scheme and map matching with particle filtering. The experiments were performed in real-time with inertial sensors of the smartphone and developed smartphone application. According to the results, the proposed scheme outperforms the conventional scheme. In the proposed scheme, step distance of the pedestrian of proposed scheme is estimated based on feature of the time domain by considering the limited battery capacity of the mobile device. The application of the link width also is proposed to remove the problem that exists only on the link method. In addition, it is shown that the proposed scheme operates well without wireless infrastructure. In the future, we are planning for the optimization of the particle filter weight and the number of particle to improve performance. Finally, for performance evaluation of the proposed scheme, experiments will be performed in the complex and various indoor environments.

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References: