

# Fusion of Integration and Parametric Approach in Smartphone-based System for Multi-pose

So Young Park<sup>1</sup>[0000-0001-5491-6776], Jae Hong Lee<sup>1</sup>[0000-0002-8222-5435], Hyunwoong Kang<sup>1</sup>[0000-0002-6875-2036] and Chan Gook Park<sup>1</sup>[0000-0002-7403-951X]

<sup>1</sup> Dept. of Mechanical and Aerospace Engineering/ASRI, Seoul National University  
Seoul 08826, Republic of Korea  
chanpark@snu.ac.kr

**Abstract.** In this paper, the fusion of IA (Integration Approach) and PA (Parametric Approach) in smartphone-based PDR (Pedestrian Dead Reckoning) is proposed for the continuous position estimation including placement change while walk. The conventional localization methods using a smartphone is mostly based on PA, which is composed of step detection, step length estimation, and heading estimation. When the device heading and walking direction do not match, then the position error rapidly increases, on the other hand, the IA based system can detect the difference between them. Therefore, the IA based PDR system with the measurement of PA is proposed in this paper. The system fuses PA and IA when the directions match, and updates based on IA if they do not match. The algorithm is tested with a commercial sensor, which shows that the proposed method can be applied in continuous localization with PDR in changing motions for smartphones.

**Keywords:** Integration Approach, Parametric Approach, Multi-pose Smartphone Navigation.

## 1 Introduction

The growing interest in human localizations inside building leads to active researches in indoor positioning. Indoor navigation for a pedestrian is largely classified into two general types: the infrastructure based system [1-2] and the self-contained system independent from external signal [3-9]. A PDR (Pedestrian Dead Reckoning) using inertial sensors is one of the examples of the self-contained system.

The PDR system can be largely categorized by its mounting position: IA (Integration Approach) and PA (Parametric Approach). The IA based PDR system calculates position by integrating inertial sensors, and measurements such as zero velocity update or contact phase velocity update are used to prevent the exponential error growth in integration[3-5]. This system requires finding the exact stance phase for zero velocity measurements; therefore, it is applied in the sensor attached on the foot. PDR using PA, however, estimates the current position by estimating the heading and distance from the previous step using a parametric approach such as walking frequency [6-9]. Once a step is detected, it only requires to calculate current heading and the

length between them, so the mounting position of the sensor is unrelated as long as the direction of the device and walking corresponds. A popular application for PA method is a smartphone, but the prerequisite is the heading match. Smartphone carried by hand is normally unconstrained, there is frequent device heading change which does not correspond with the walking direction. In order to remove the heading offset between them, several researchers tried to solve the problem, but there are still large position errors [6-8].

As mentioned earlier, the IA based PDR calculates position, velocity, and attitude by acceleration and angular velocity, so it is not affected by the error from walking direction. Therefore, we combine advantages of both IA and PA to for smartphone PDR system. It is necessary for IA to be compensated to suppress the error growth, so step length and heading from PA are used as a measurement when the direction corresponds. Once the device heading does not match with the walking direction, the position is calculated from the IA, but the measurement is only a step length which is not affected by the position in our system.

The rest of paper is organized as follows. Section 2 introduces PA-based PDR which is commonly used for smartphone-based position estimation. Section 3 presents the specific logic of IA and PA fused PDR system. The experimental result with discussion is provided in Section 4, and the conclusion is described in Section 5.

## 2 PA Based PDR

Position from PA-based PDR system is calculated and largely composed of three components: step detection, step length estimation and heading estimation between successive two steps. With the estimated components, the position is calculated as Eq. 1.

$$\begin{bmatrix} p_{n,k} \\ p_{e,k} \end{bmatrix} = \begin{bmatrix} p_{n,k-1} + Steplength \cdot \cos(\psi) \\ p_{e,k-1} + Steplength \cdot \sin(\psi) \end{bmatrix} \quad (1)$$

where  $k$  is  $k$ -th step, and  $p_{n,k-1}, p_{e,k-1}$  is previous position and  $\psi$  is device heading. The following subsections explain each method in detail.

### 2.1 Step Detection

Accurate step detection is the basis of PA-based PDR method for the precise position estimation. Even if the step length is accurately estimated, errors from missing or addition of a single step can be considerable due to inaccuracies in the step detection process.

The conventional step detection techniques such as the peak detection and the zero-crossing detection use the outputs of accelerometers and gyros. The peak detection method is able to find a step periodically by detecting the moment that foot touches the ground, heel strike. In this paper, the peak detection method is implemented using

an acceleration norm given this advantage of detecting heel strike. In order to prevent the noise effect, a first-order low pass filter (LPF) with a cut-off frequency set to 2Hz.

## 2.2 Step Length Estimation

As the name implies, the distance between two steps, step length, from PA is determined by its parameters. The one from IA, on the other hand, is from the double integral of the accelerometer outputs, which lead to large error.

Following the linear relation between step length and step frequency, we use the step length estimation method based on the linear combination similar to the previous work [9]. There are numerous features and functions to estimate step length other than the walking frequency, but it is advantageous for the independency of the mounting position as long as the step is correctly detected. This following equation is the step length formula applied.

$$\text{Step Length} = \alpha \cdot WF + \beta \quad (2)$$

where  $WF$  is walking frequency and  $\alpha, \beta$  are pre-learned parameters according to the pre-calibration.

## 2.3 Heading Estimation

In the assumption under PA-based PDR, the device direction is the same as the walking direction. The attitude of the smartphone is commonly estimated through gyroscopes, accelerometers, and magnetometers, which is called an AHRS (attitude heading reference system). For roll and pitch, the AHRS integrates the output of the gyroscope under stationary accelerometer condition. If the tilt angle is estimated accurately, the magnetometers can be combined with the gyro to estimate yaw in relation to the earth's magnetic field. However, it is necessary to consider the magnetic disturbance in the surrounding environment.

# 3 IA and PA Combined PDR

In this section, we propose IA and PA fused PDR for the handheld condition with walking direction and device heading not corresponding as in Fig. 1 and there are three different ways to use measurements. Firstly, if the direction of the device is constant with a small heading difference between two methods and step length is also considered as normal walk, the heading offset is also constant. In this case, both step length and walking direction from PA are used as the measurements to compensate the IA. When the device direction from PA does not match with IA with normal step length, only PA step length is used as the measurement value, whose stage is considered as walking with heading difference such as calling pose. Additionally, if it is judged that walking is too short, only pure INS is performed, which is also effective in step length error at rotation and transition between motions. To implement the pro-

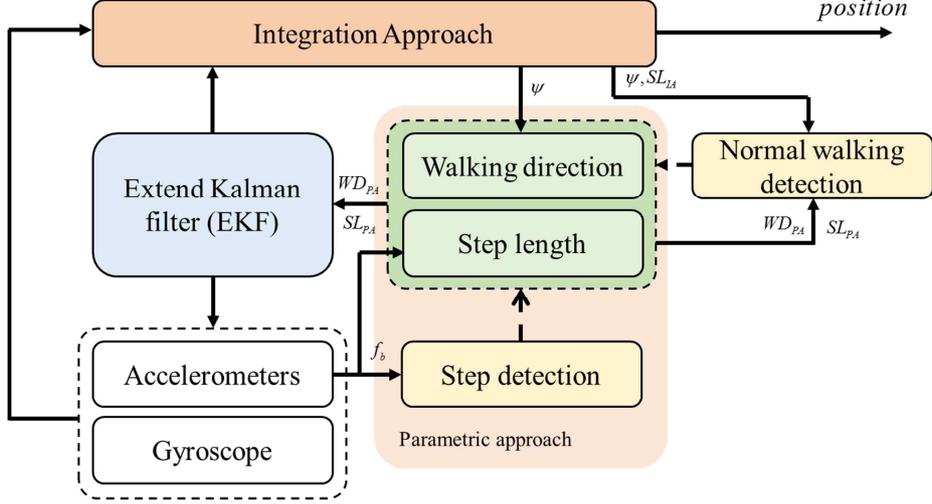


Fig. 1. IA and PA combined PDR system

cedures described above, we set the filter state and corresponding state transition matrix as follows:

$$\delta x = [\delta p_D, \delta p_{IA,step}, \delta v, \delta \varphi, \delta b_a, \delta WD_{offset}]^T \quad (3)$$

$$\Phi = \begin{bmatrix} 1 & 0 & dt & 0 & 0 & 0 \\ 0 & I_{2 \times 2} & \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \cdot dt & 0 & 0 & 0 \\ 0 & 0 & I_{3 \times 3} & S_{3 \times 2} \cdot dt & C_b^n \cdot dt & 0 \\ 0 & 0 & 0 & I_{2 \times 2} & 0 & 0 \\ 0 & 0 & 0 & 0 & I_{3 \times 3} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

where  $\delta p_D$ ,  $\delta p_{IA,step}$ ,  $\delta v$ ,  $\delta \varphi$ ,  $\delta b_a$ ,  $\delta WD_{offset}$ ,  $S$  are position error, 2D step error during step, velocity error, attitude error, accelerometer bias error, walking direction offset while PA and IA corresponds, and skew symmetric matrix of acceleration in navigation frame, respectively. As mentioned above, the proposed algorithm operates in three modes depending on the situation.

First, if the direction of the device and walking direction corresponds, we assume that the offset is also constant, which in turn is able to use step length and walking direction as measurements. In addition, the vertical position for every step similar, it is also used for the update. If the IA position is too short, it is considered as motion transition and rotating in place, and there is no measurement update but only IA position is chosen as a current position. This is advantageous to prevent the PA position errors from misdetection, wrong heading estimation during the transition.

The measurement model and its matrix are as follows and it is selectively used according to the device condition mentioned earlier:

$$z = [WD_{IA} - WD_{PA} - WD_{offset}, \quad SL_{IA} - SL_{PA}, \quad P_{D,k} - P_{D,k-1}]^T \quad (5)$$

$$H = \begin{bmatrix} 0 & -\frac{P_{IA,step,E}}{P_{IA,step,N}^2 + P_{IA,step,E}^2} & \frac{P_{IA,step,N}}{P_{IA,step,N}^2 + P_{IA,step,E}^2} & \mathbf{0}_{1 \times 8} & -1 \\ 0 & \frac{P_{IA,step,N}}{\sqrt{P_{IA,step,N}^2 + P_{IA,step,E}^2}} & \frac{P_{IA,step,E}}{\sqrt{P_{IA,step,N}^2 + P_{IA,step,E}^2}} & \mathbf{0}_{1 \times 8} & 0 \\ 1 & 0 & 0 & \mathbf{0}_{1 \times 8} & 0 \end{bmatrix} \quad (6)$$

## 4 Experimental Results

To compare and prove the performances of conventional PA-based PDR system and the proposed method, tests are firstly performed with Xsens MTI-300 which is an IMU module having better performance than commercial smartphones [10]. The walking scenario is a straight-line trajectory with 42m for one way northward. On the way back to the starting point, the subject switches from an action that held the phone in the hand to an action to receive a call. The handheld motion is a situation in which the direction of movement is in the same as the direction of the device, whereas the call receiving motion represents a situation where the two directions are inconsistent. The x-axis in Fig. 2 represents east distance, and the y-axis is north, respectively. The area with green color in Fig. 2 is "calling pose" on the way back. The proposed algorithm shows higher performance than the conventional algorithm because it improves the accuracy of step length and walking direction. Especially, it can be confirmed that the position is accurately estimated even when the walking direction and the device direction are different. Therefore, the algorithm can be applied in other situations with heading discordance. Even though the proposed algorithm seems to work well, but if the condition depending only on IA continues for a long time, the heading error increases greatly over time. In that case, the additional heading measurement such as dominant direction could improve the performance with IA, which is considered as future work. In addition, IA position error is compensated based on the performance of step length from PA, so it is still required to have a reasonable length estimation on average.

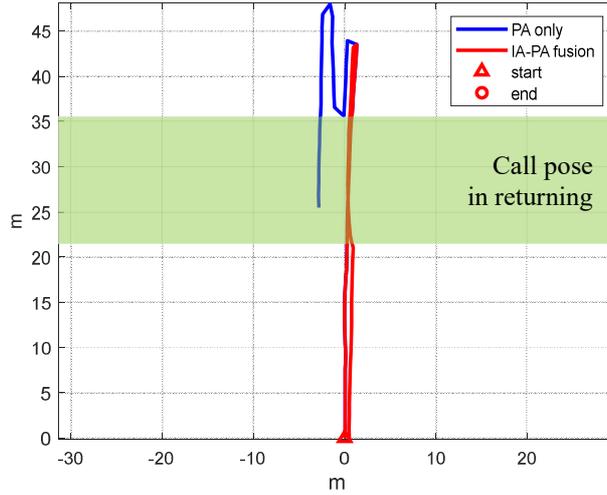


Fig. 2. Performance comparison between PA method and proposed IA-PA method

## 5 Conclusion

In this paper, we proposed the fusion of IA and PA-based PDR system that can be applied to discrepancies in walking direction during walking. The proposed system constructs the filter with IA propagation with the selective measurement from PA depending on the device heading correspondence. If there is no heading difference between two systems, heading and step length from PA compensate IA. When there is a heading offset from motions, then the distance is only used as a measurement to prevent the error growth in IA. The IA also used for the short term during the transition phase between motions. Through experiments, it is possible to apply the proposed algorithm for the indoor navigation, which shows noticeable improvement under changing and different motions while pedestrian walks.

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