An Improving Pedestrian Navigation Method Based on Low Cost AHRS

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Abstract. Aiming at the problem of the poor observability for the yaw measurement of the foot-mounted attitude heading reference systems (AHRS), this paper presents an indoor pedestrian navigation method using low cost foot-mounted AHRS and waist-mounted compass. Based on this mode, the yaw measured from the waist-mounted compass is used to calculate the attitude transformation matrix for the foot-mounted AHRS, and then the Kalman filter (KF) is used to restrict the error of the inertial sensors when the person is in a stance phase during walk. The experimental results showed that the mean error of the position had been reduced by about 28% when compared with the method without the waist-mounted compass, which demonstrated the effectiveness of the proposed method.

Introduction

Pedestrian Navigation (PN) which tracks the location of a person has received great attention over the past few decades [1]. Although the Global Positioning Systems (GPS)-based PN has been widely used, there are still many challenges in GPS denied areas, especially in the indoor environment. To provide the accurate location of a person indoor with low requirements, many proposals based on Inertial Navigation System (INS) have been put forward [2]. For example, J.-L. Zhang et al. proposed the shoe-mounted personal navigation system using MEMS inertial technology [3], A. Ali et al. designed the MEMS-based PN for GPS-denied areas in [4], V. Renaudin et al. and S.H. Shin et al. presented the step length estimation methods for PN [5,6], J. Bird et al. utilized the foot-mounted strapdown inertial navigation for indoor navigation [7]. The system based on the framework of foot-mounted Inertial Measurement Unit (IMU) is one of the most widely used methods for PN that was proposed by E. Foxlin in [8], in which Zero-velocity update (ZUPT) was used to reduce the drift errors. It should be point out that the foot-mounted IMU framework can achieve good performance even by the low cost IMU, but cannot provide the long-time available navigation information due to its unobservable heading of the scheme. In order to overcome this problem, some researchers have tried to reduce the yaw drift by using the magnetic sensors (such as in [2,7]) or some geographical features (such as in [9,10]). However, there are some shortcomings in these methods, for example the foot-mounted magnetic sensors are poor in yaw calculation for PN due to its strong vibration during the normal walking, the geographical features should be known in advance, and so on.

In order to achieve low cost indoor pedestrian navigation, an improving low cost indoor pedestrian navigation method is proposed in this work. Firstly, we employ some constraints to restrict the INS error when the person is in a stance phase during walk. Meanwhile, waist-mounted compass is used to compute the yaw of the person, which is able to improve the accuracy of the yaw for the foot-mounted AHRS. The organization of this paper is as follows. In Section 2, the drift reduction methods for foot-mounted AHRS are presented, which contains the Kalman filter for the drift reduction in a stance phase during walk and the improving pedestrian navigation method using waist-mounted compass. In Section 3, the indoor tests and discussion are illustrated. Finally, the conclusions are drawn.
Drift Reduction Methods for Foot-Mounted AHRS

In this section, the drift reduction methods for foot-mounted AHRS will be given. The coordinate frames used in this work are shown in Fig.1, which includes the body frame (in short, b-frame) and the navigation frame (in short, n-frame). In this work, since the smaller indoor navigation area, the influence of the earth's rotation will be neglected.

Kalman Filter for the Drift Reduction in a Stance Phase during Walk

In this work, when the person is in a stance phase, the error state vector \( \delta X = [\delta \phi, \delta V^e, \delta P^e, \delta \omega, \delta \omega^e] \) of the Kalman filter (KF) is used for the error estimation, which contains 15 elements. \((\phi, \delta V^e, \delta P^e)\) represent the errors of attitude, velocity, and position in n-frame, and \((\omega, \delta \omega^e)\) represent the biases of the accelerometers and gyroscopes in n-frame. Each of these 5 components has 3 elements. The state equation can be obtained in Eq. (1),

\[
\begin{bmatrix}
\delta \phi_{k+1} \\
\delta V^e_{k+1} \\
\delta P^e_{k+1} \\
\delta \omega^e_{k+1} \\
x_{k+1} 
\end{bmatrix}
= \begin{bmatrix}
I_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & I_{3 \times 3} \cdot T \\
0_{3 \times 3} & I_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} \\
0_{3 \times 3} & 0_{3 \times 3} & I_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} \\
0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & I_{3 \times 3} & 0_{3 \times 3} \\
0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & I_{3 \times 3} \end{bmatrix}
\begin{bmatrix}
\delta \phi_k \\
\delta V^e_k \\
\delta P^e_k \\
\delta \omega^e_k \\
x_k 
\end{bmatrix}
+ \omega_k .
\]

(1)

Where, \( S(f_i) = \begin{bmatrix}
0 & a_{xk}^e & -a_{Nk}^e \\
-a_{xk}^e & 0 & a_{Nk}^e \\
a_{Nk}^e & -a_{xk}^e & 0
\end{bmatrix}\), and \( [a_{xk}^e, a_{Nk}^e, a_{uk}^e] \) is the acceleration in East, North, and Up respectively, \( T \) is the sampling period, \( \omega_k \) is the Gaussian white noise with zero mean, and its covariance matrix is \( Q_k \).

The measurement equation for KF is illustrated in Eq. (2),

\[
\begin{bmatrix}
\delta V^e_k \\
\delta P^e_k \\
\delta \omega^e_k \\
x_k 
\end{bmatrix}
= \begin{bmatrix}
0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} \\
0_{3 \times 3} & I_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} \\
0_{3 \times 3} & 0_{3 \times 3} & I_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} \\
0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & I_{3 \times 3} & 0_{3 \times 3} \\
0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & 0_{3 \times 3} & I_{3 \times 3} \end{bmatrix}
\begin{bmatrix}
\delta \phi_k \\
\delta V^e_k \\
\delta P^e_k \\
\delta \omega^e_k \\
x_k 
\end{bmatrix}
+ \eta_k .
\]

(2)
Where, $\delta V^e_k$ and $\delta \omega^b_k$ are the observations for the velocity error vector and the biases for gyroscopes in n-frame respectively. $\eta_k$ is the Gaussian white noise with zero mean, and its covariance matrix is $R_k$.

When the person is in a stance phase, the velocity and the angular velocity measured by INS should be zero, however, this value is not zero in practice. Thus, there exists the following equation,

$$
\begin{bmatrix}
\delta V^e_k \\
\delta \omega^b_k
\end{bmatrix} =
\begin{bmatrix}
V^\text{INS}(0) - 0_{3x3} \\
Gyro^\text{INS}(0) - 0_{3x3}
\end{bmatrix}
$$

(3)

Where, $V^\text{INS}(0)$ and $Gyro^\text{INS}(0)$ are the velocity and the angular velocity of the INS when the person is in a stance phase. The equations utilized in the algorithm of KF are as follows:

$$X_{k+1} = F_k X_k + \omega_k$$

(4)

$$P_{k+1} = F_k P_k F_k^T + Q_k$$

(5)

$$K_k = P_{k+1} H_k ^T \left( H_k P_{k+1} H_k ^T + R_k \right)^{-1}$$

(6)

$$X_k = X_{k+1} + K_k \left( Z_k - H_k X_k - \eta_k \right)$$

(7)

$$P_k = \left[ I - K_k H \left( X_k \right) \right] P_{k+1}$$

(8)

**Improving Pedestrian Navigation Method Using Waist-Mounted Compass**

The foot-mounted AHRS has advantages in reducing the velocity error of INS [11]. However, the disadvantage of it is that the strong vibration during normal walking will result in poor yaw measurement. In order to overcome this problem, an improving pedestrian navigation method using foot-mounted AHRS and waist-mounted compass is proposed in this work. The configuration of the navigation method is shown in Fig. 2. In this mode, the yaw measured from the waist-mounted compass is used for the navigation calculation of INS, which is able to improve the accuracy of the attitude transformation matrix for the foot-mounted AHRS. When the person is in a stance phase, the KF is used for INS error estimation with the state equation and the measurement equation mentioned in Eq. (1) and Eq. (2). And then, the navigation calculation of INS will be corrected.

**Indoor Tests and Discussion**

**Indoor Test Environment**

In this work, a real indoor test was carried out to evaluate the performance of the proposed method. The test platform is made up of 2 sets of 9 DOF AHRS. One is fixed on a shoe, and the other one is
fixed on the waist. The foot-mounted AHRS employs ADXL203, ADXRS620, and HMC5983 as accelerometer, gyroscope, and magnetometer respectively, while the waist-mounted compass employs MPU6050 and HMC5883 as accelerometer, gyroscope, and magnetometer respectively. Meanwhile, an encoder and an AHRS are used to provide the reference trajectory. The encoder is used for measuring the walking velocity and the AHRS (consists of MPU6050 and HMC5883) is used for measuring the yaw. And the computer is used for the data collection.

**Yaw Measurement in Different Parts**

In this section, the yaw measurement in different parts will be discussed. In this work, to achieve the best performance for the test, one AHRS is fixed on three different parts of the body which contains the foot, waist, and head. Fig.3 illustrates the yaw measurement errors from the AHRS fixed on the aforementioned three parts when the person walks along a straight line. Evidently, the yaw measurement error from the AHRS fixed on the waist is better than the AHRS fixed on the other parts. What’s more, the rotation of the waist is smaller than that of the head and the foot during this movement.

![Figure 3. The yaw measurement error in different parts when the person walks along a straight line.](image)

**The Performance for the Proposed Navigation Method**

In this section, the performance for the proposed navigation method will be discussed. Fig. 3 shows the yaw measured from the foot-mounted AHRS and the yaw measured from waist-mounted compass. It is obvious that both of the foot-mounted AHRS and waist-mounted compass are able to measure the yaw of the person, but the yaw measured from the foot-mounted AHRS has a strong vibration when compared with that from waist-mounted compass.

![Figure 4. The positioning result in rectangle route experiment.](image)

In Fig.4, the trajectories of the two schemes are shown, which contains the method proposed in this work and the method only used the foot-mounted AHRS proposed in [11]. Obviously, the proposed method is more effective when compared with the other one. The comparison for the position errors of two schemes is showed in Tab. 1, which demonstrates that the proposed method has the lowest error in the east and north direction respectively. The mean root-mean-square error (RMSE) of position for the proposed method is 0.345m, and it has reduced the mean RMSE of position by about 28.2% compared with the method proposed in [11].
**Table 1. Comparison of two strategies in terms of position error.**

<table>
<thead>
<tr>
<th>Method</th>
<th>RMSE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
</tr>
<tr>
<td>The method proposed in [11]</td>
<td>0.55</td>
</tr>
<tr>
<td>The proposed method</td>
<td>0.46</td>
</tr>
</tbody>
</table>

**Conclusions**

In this work, an improving indoor pedestrian navigation method using low cost foot-mounted AHRS and waist-mounted compass is proposed. In order to achieve good performance for the yaw measurement of a person, one AHRS is fixed on the waist, which is used as the waist-mounted compass. The yaw measured by the waist-mounted compass is used to calculate the attitude transformation matrix for the foot-mounted AHRS. The experimental results show that the proposed method is effective to reduce the mean error of the position by about 28% when compared with the method without the waist-mounted compass.

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**References**


