Research on Improved Pedestrian Dead Reckoning Algorithms

Sen-xin HAO, Qiang YU and Ya-fei QIAN*

Department of Computer and Software Engineering, XI HUA University, Chengdu, Sichuan Province, China
*Corresponding author

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Abstract. In view of user's requirements of high performance, easy operation and low cost with indoor location, data acquisition software based on Android platform utilize sensors built-in cellphone is used to study the pedestrian dead reckoning (PDR). Step detection and step length estimation are carried out by collecting leg swing angle while walking, and the classical step length estimation algorithm is improved. At the same time, the improved heuristic drift elimination algorithm is used to calculate the direction. Finally, the experiment results show that the PDR technology can better satisfy the requirements of indoor pedestrian positioning, and as for the low-cost multi-sensor, compared with the existing algorithm, the improved algorithm with higher positional accuracy.

Introduction

In recent years, with the introduction of the concept of intelligent space and the development of technology in this field, giving location based service (LBS) plays an increasingly important role in many fields of social life, such as pedestrian navigation, fire safety, peripheral push and so on. Outside, GPS can bring great convenience to outdoor users, but in the indoor environment, because of the influence of building wall and various facilities in the building, the performance of GPS[1] will degrade greatly, which cannot provide effective location information. How to accurately obtain pedestrian location information in complex indoor environment has always been an academic problem with research space and development space, so in recent years, indoor positioning technology has gradually become a hot research topic[2].

In the field of indoor positioning, there have been many outstanding research achievements, such as establishing fingerprint database through received signal strength, identifying pedestrian location information by signal intensity matching or other positioning algorithms. However, these methods need to deploy beacon nodes ahead of time, and the hardware cost is also higher. Because the signal may be interfered, the accuracy of this kind of positioning algorithm is generally about 1 ~ 3m[3]. Pedestrian dead reckoning (PDR) technology uses inertial sensors, acceleration sensors and gyroscopes to calculate the walking track of a person by using the direction data collected in the course of human walking and calculating the step length. The positioning error is generally about 2m.

At present, there are two methods of pedestrian dead reckoning, one is based on traditional inertial navigation technology and the other is based on pedestrian step detection positioning technology respectively. The traditional inertial navigation technology is generally used in inertial navigation system (INS). This theory is based on Newton's law of mechanics. The motion acceleration of target relative coordinate system is measured by accelerometer. And the twice integration of the acceleration can be used to determine the distance traveled by the target so as to determine the position of the target. This method has no limitation on meteorological environment and is widely used in aerospace. In inertial navigation system, it is necessary to compensate the error of accelerometer. In addition to eliminating the linear limiting factor and the fixed deviation, the residual factor of the error will produce a great distance error with time. In order to eliminate this error, we need to continuously use zero speed update. The basic principle of zero speed update is to clear the integral velocity when the
target is in static condition, but in the pedestrian navigation and positioning system, the walking is not interrupted frequently, so this method is no longer applicable.

The key elements of pedestrian step detection technology are: step detection, step length calculation, direction calculation, the sensor accuracy requirements are not high, but also reduce the computation complexity, which is suitable for pedestrian navigation. Most of the algorithms in this technique are based on the change of acceleration period to detect the pace, which will be greatly affected by the pavement. Based on the angle of leg swing during walking, the pedestrian step detection and location algorithm adopted in this paper is independent of the road surface, and the estimation accuracy of step length is high.

**Step Detection**

By observing the characteristics of leg swing in normal human walking, it is found that the angle of leg swing during walking is periodic. When the first step of the mobile phone’s side is taken, the angle reaches the peak $\theta_{\text{max}}$. When the leg on the other side takes the second step, the swing angle of the upper leg reaches the minimum value $\theta_{\text{min}}$. Because the same phone cannot be placed in both pockets at the same time, when the whole peak detection step is complete, the pedestrian has taken two steps.

Because the swing angle of the leg can't be beyond the normal range when walking, and the time taken for each step also has a normal range, the number difference and time difference between the detected $\theta_{\text{max}}$ and $\theta_{\text{min}}$ should not be greater than a specific threshold. Whether $\theta_{\text{max}}$ and $\theta_{\text{min}}$ are detected in the threshold range, the pedestrian can be judged whether or not he is walking or not.

![Figure 1. Legend of walking.](image)

**Step Length Estimation**

By consulting the previous literature, it is known that the step length is proportional to the difference between $\theta_{\text{max}}$ and $\theta_{\text{min}}$. And the Eq. 1 and Eq. 2 represent the classical step length estimation equation:

$$\Delta \theta = \theta_{\text{max}} - \theta_{\text{min}}$$  \hspace{1cm} (1)

$$L = K \cdot \Delta \theta + b.$$  \hspace{1cm} (2)

In the Eq. 2, the parameters k and b are fitting parameters.

Through the observation of the actual movement of the pedestrian walking, it is easy to find that although the angle of leg swing reaches the maximum when $\theta_{\text{max}}$ appears, however the leg of the raised side does not hit the ground at this time. During the landing, the foot will have the action of retraction. The angle at which the leg swing on the actual landing is reduced, so the estimated step length of the Eq. 2 is larger than the actual step length.

In order to improve the Eq. 2, it is first necessary to study the state of the human body when the step length is generated, that is, when both feet are in contact with the ground, where, in order to keep
balance between the legs and the ground, there is almost an equilateral triangle. At the same time, the leg swing angle will also be collected, so the classical equation of step length estimation Eq. 2 can be optimized to the improved Eq. 3:

\[ L = K \cdot 20\min + b. \]  

(3)

The parameters in the equation are different from person to person. Different people have different height and leg length, and the corresponding parameters will be different. In order to fit a calculation equation of step length that is worth popularizing, in this paper, five people with different sizes are selected to walk in a straight path with small steps and big strides respectively. The relationship between step length and 20 min is recorded (all the steps in this paper are the sum of two steps), and a linear fitting equation is established, as shown in the Fig. 2, at least 85% of the data can be explained by linear fitting equations[6].

Figure 2. The relationship between leg swing angle and step length of different people.
Through the optimization of five groups of data by using the least square method, the optimal values of \( k \) and \( b \) are fitted, and a generalized equation is obtained, which is shown in the Fig. 2, in which the rough lines represent the generalized equation.

In order to verify that the improved Eq. 3 is more accurate in estimating the step length than the previous one Eq. 2, select a straight line path, walk 12 times at a normal pace, and remove the first and last times, take the middle 10 times to do the test, get the data of the following table.

| Eq. 2 | Eq. 2 estimate value | Measured Value | Eq. 3 estimate value | Eq. 3 relative error |
|-------|----------------------|---------------|----------------------|----------------------|
| 0.96% | 1.362                | 1.349         | 1.357                | 0.59%                |
| 1.54% | 1.318                | 1.298         | 1.314                | 1.23%                |
| 0.46% | 1.303                | 1.297         | 1.296                | 0.07%                |
| 0.61% | 1.306                | 1.298         | 1.303                | 0.38%                |
| 1.00% | 1.314                | 1.301         | 1.311                | 0.77%                |
| 1.14% | 1.327                | 1.312         | 1.323                | 0.83%                |
| 0.70% | 1.303                | 1.294         | 1.299                | 0.38%                |
| 0.69% | 1.319                | 1.310         | 1.309                | 0.07%                |
| 1.01% | 1.288                | 1.275         | 1.282                | 0.55%                |
| 0.23% | 1.304                | 1.307         | 1.309                | 0.15%                |

### Direction Calculation

The inertial sensor gyroscope in a smart phone is a device that can measure the angular velocity of mobile phone motion. Although it has short-term accuracy, the directional error derived from the angular velocity integral increases over time, and the mobile phone's moving track is not regular. In addition, gyroscopes provide the relative direction of mobile phone movement rather than the direction of the world coordinate system, even if the mobile phone coordinate system is converted into the world coordinate system, there is also understeer effect[7]. Therefore, the direction obtained by gyroscopes only is not completely reliable and cannot be directly used to judge the movement direction of pedestrian carrying mobile phones.

![Figure 3. Mobile phone coordinate system.](image)

![Figure 4. World coordinate system.](image)
Heuristic drift elimination (HDE) algorithm can effectively reduce the direction error caused by gyroscope drift[8], but the restrictive condition of HDE algorithm is that: pedestrian paths must be vertical or parallel to each other, although most buildings today meet this condition, but the HDE algorithm stops correcting during turns, and gyroscope offsets begin to accumulate errors[9]. The direction error will be eliminated only when the HDE algorithm resumes operation.

In this paper, an improved heuristic drift elimination (HDE) algorithm, on the base of HDE, this algorithm adds curves and corrections to gyroscope offset error during turns. The steps are as follows:

1) In the initial state, the angular velocity of gyroscope rotating along Y axis is set to the current direction of pedestrian. By integrating the Y axis of gyroscope at the beginning point and the end point in a footstep detection process, the increment angle $\Delta \Psi_i$ is obtained.

2) The HDE algorithm is used in the walking path of a straight line, and the turning or curve track is switched to the improved algorithm. Eq. 4,Eq. 5,Eq. 6 describes how the algorithm can judge whether the walking track is a straight line or not.

$$T = 0 \ , \ |\Psi_{i-1} - \Psi_{i-2}| < Th$$  \hspace{1cm} (4)

$$T = 1 \ , \ |\Psi_{i-1} - \Psi_{i-2}| < Th \cap \Psi_{i-1} > \Psi_{i-2}$$ \hspace{1cm} (5)

$$T = -1 \ , \ |\Psi_{i-1} - \Psi_{i-2}| > Th \cap \Psi_{i-1} < \Psi_{i-2}$$ \hspace{1cm} (6)

3) The compensation process of HDE on a straight line is shown in Eq. 7,Eq. 8, Eq. 9, where $I_i$ represents the compensation value of the HDE algorithm in step I, C is a small constant increment, which is used to compensate the direction error, and n is the sampling number in a detection step.

$$I_i = I_{i-1} - n\cdot c \ , \ \Psi_{i-1} > 45^\circ$$ \hspace{1cm} (7)

$$I_i = I_{i-1} \ , \ \Psi_{i-1} = 45^\circ$$ \hspace{1cm} (8)

$$I_i = I_{i-1} + n\cdot c \ , \ \Psi_{i-1} < 45^\circ$$ \hspace{1cm} (9)

4) The direction of the HDE estimation will oscillate in the main direction. To reduce this oscillation, $I_i$ is limited to 0, as in Eq. 10:

$$I_i = 0 \ , \ (\Psi_{i-1} - 45^\circ)(\Psi_{i-2} - 45^\circ) \leq 0$$ \hspace{1cm} (10)

5) Controller receives signals $T$ and $I_i$ when $T = 0$, directly outputs $I_i$; when $T \neq 0$, PSP uses the mobile phone swing on the straight line path to average the value of each detection step on the line as a compensation value for understeer. The output of the controller can be expressed as Eq. 11,Eq. 12:

$$P = I_i \ , \ T = 0$$ \hspace{1cm} (11)

$$P = T \cdot I_i \ , \ T \neq 0$$ \hspace{1cm} (12)

6) The direction of pedestrian walking can eventually be expressed as Eq. 13

$$\Psi_i = \Delta \Psi_i + \Psi_{i-1} + P$$ \hspace{1cm} (13)

Experimental Results and Analysis

In this section, experiments are made on the application of the above dead reckoning algorithms, and the effects of two step length algorithms on the results of pedestrian dead reckoning are compared. This experiment uses the vivoX21 mobile phone as the experimental equipment to collect the data.
The experiment site selects a circle of corridors on the fifth floor of the sixth teaching building of Xihua University. The site is rectangular and meets the requirements of the algorithm for the route and it has both straight and turning routes.

The route of the experiment site is shown in the Fig. 5. is a closed rectangle with a length of 72m and a width of 46m. The star mark point is the starting point, and then walking clockwise back to the star mark point. In the experiment, two volunteers of different height and weight walked on the designated route of the experiment site, two people put the mobile phone vertically in their pants pocket and walked at a constant and stable speed, and they used two step length algorithms to walk through the same route respectively, and four groups of data were obtained.

The obtained data is processed in the MATLAB simulation software. The following Fig. 6 and Fig. 7 show the estimation results of two step length algorithms[10]. The blue dotted line represents the real path, and the red asterisk represents the positioning result of the improved step length algorithm. Black squares represent the positioning results of classical step length algorithms.

![Figure 5. Map of experiment site.](image)

![Figure 6. Location result of volunteer1.](image)
Because the step length of the classical step estimation method does not take into account that the step length will be reduced when the leg lifts and falls to ground, the step length is always larger, and the error accumulation leads to the positioning result farther than the real position. The improved step length estimation method is obviously superior to the classical step length estimation method in the positioning effect, and the error is reduced by about 10%, because of the error of the sensor and the algorithm itself[11], there is a little deviation between the positioning track and the real path of the improved step length estimation method, but it is also within the range of accuracy, which meets the requirements of the design index.

Summary and Prospect

With the development of Micro-Electro-Mechanical System (MEMS) and the upgrading of smart phone, it has been a research hot spot in the field of positioning to study indoor positioning technology using smart phone as hardware platform and using the rich sensors of smart phone as assistant. This paper discusses in detail three modules of PDR algorithm, such as step detection, step length estimation and direction calculation, and optimizes the classical step length estimation algorithm by studying the movement of walking and the angle of leg swing. The effect of reducing the positioning error is obvious and the ideal positioning accuracy is obtained. However, due to the limited performance of the sensor and the accumulation of errors[12] in the PDR algorithm after a long walk, the longer the time is, the bigger the error is, so the algorithm can only be used for short distance positioning. The next step will be to use PDR algorithm combined with WIFI[13] to make positioning, which can not only make up for the deficiency of WIFI signal being easily interfered, but also realize long time and long distance PDR positioning.

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