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Research on Heading Constraint Algorithm of Pedestrian Inertial Navigation

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Abstract

In order to solve the problem of serious divergence of positioning results from pure inertial navigation of low-precision inertial positioning terminal, a heading constraint method for pedestrian inertial navigation is proposed to suppress the course drift of low-precision inertial positioning equipment and prolong the service life of low-precision inertial positioning terminal. The deviation between the heading angle and the main heading is used to estimate the heading angle error, and a pedestrian heading constraint algorithm model based on extended Kalman filter is established. The experimental results show that the method can effectively suppress the heading drift of the low precision inertial positioning terminal and reduce its positioning cumulative error.

Keywords

Inertial Navigation; Kalman Filtering; Course Constraint.

1. Introduction

Non autonomous navigation mainly includes satellite navigation. In some harsh environments (such as closed underground space, complex indoor space, etc.), the satellite signal will be interfered, resulting in serious loss of positioning accuracy, and even the positioning result is completely unavailable. Compared with this, autonomous navigation mainly refers to inertial navigation. Inertial navigation technology mainly has the advantages of autonomous navigation, no need to arrange points in advance or install additional infrastructure. However, the current inertial navigation technology also has some problems such as high cost of high-precision inertial sensors and large accumulated error in long-term work of inertial positioning system [1].

At present, there are many researches on the methods to improve the positioning accuracy of inertial positioning system, such as the research of high-precision inertial sensor devices, the research of data fusion based on Wi Fi fingerprint, geomagnetic database, visual information and inertial positioning information, etc [2], but most of the researches need to use external information, or need to establish some databases or arrange points in advance. In order to solve the problem of large drift error of inertial sensor used in low precision inertial positioning terminal, which results in large accumulated short-term positioning error, an improved HDE algorithm is proposed to constrain the course of low-precision inertial positioning terminal.

2. Fundamental

2.1 Pedestrian track estimation principle

Pedestrian Dead Reckoning (PDR) algorithm is a method of pedestrian inertial positioning technology, its basic theory is to use inertial sensors to obtain information such as acceleration, step length and heading angle during pedestrian movement, calculate the pedestrian's current location information based on the location. There are many ways to use inertial sensors to obtain pedestrian motion parameter information. The accelerometer and magnetometer can be used to obtain the initial attitude of the pedestrian, and then the gyroscope can be used to update the attitude angle of the pedestrian in real time to obtain the pedestrian's heading angle information. Pedestrian's real-time step length information can be estimated using the nonlinear model shown in formula (1) [3].

$$L_i \approx K\sqrt[4]{A_{i\max} - A_{i\min}} \tag{1}$$

In formula (1), A_{imax} and A_{imin} are the maximum and minimum Z-axis acceleration of the pedestrian at the i-th step; K is the step threshold, which needs to be set according to the pedestrian's physical characteristics.

The principle of the PDR algorithm is shown in Figure 1. The basic idea is to divide the pedestrian's walking process into single steps, and each single step calculates the pedestrian's acceleration, step length, heading and other parameters, and superimposes the step length direction vector, can calculate the current position information of the pedestrian relative to the starting point.

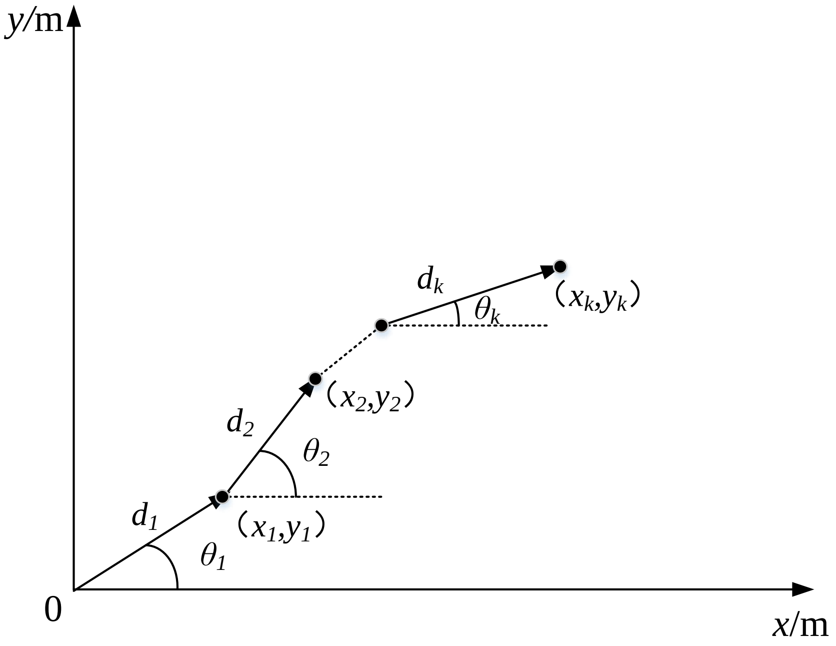

Fig. 1 Principle of PDR algorithm

Its current position coordinate relative to the starting point is derived as shown in formula (2):

$$\begin{cases} x_k = x_0 + \sum_{i=1}^{k} L_i \cos\theta_i \\ y_k = y_0 + \sum_{i=1}^{k} L_i \sin\theta_i \end{cases} \tag{2}$$

In formula (2), (x_0,y_0) represents the initial position coordinates, (x_k,y_k) represents the position coordinates at time k, L_i represents the step length of the pedestrian's i-th step, θ_i represents the heading angle of the pedestrian at step i.

2.2 Attitude calculation principle

2.2.1 Initial solution of attitude angle

At the initial moment, the roll angle and pitch angle can be obtained by using the acceleration value:

$$roll = \arctan(\frac{a_x^b}{a_z^b}) \tag{3}$$

$$pitch = \arctan\left(\frac{-a_y^b}{\sqrt{(a_x^b)^2+(a_z^b)^2}}\right) \tag{4}$$

In formula (3) and formula (4), *roll* is roll angle, *pitch* is the pitch angle. In navigation equipment without magnetometer, the initial heading angle can be set to *yaw*=0°.

2.2.2 Principle of attitude updating

The commonly used attitude description methods include Euler angle method, direction cosine method and quaternion method. Because quaternion method has the advantages of simple calculation and convenient processing, and can avoid the singularity problem caused by Euler angle, so most inertial navigation systems choose quaternion method to solve the attitude information [4].

Suppose that the projection of a vector in Cartesian coordinate system $oxyz$ and $ox'y'z'$ is $\vec{x}(x,y,z)$ and $\vec{r}(x',y',z')$ respectively, expressed by quaternion $q=[q_0\ q_1\ q_2\ q_3]^T$:

$$[x'\ y'\ z']^T = R[x\ y\ z]^T \tag{5}$$

R is the coordinate transformation matrix, and there are:

$$R=\begin{bmatrix} q_0^2+q_1^2-q_2^2-q_3^2 & 2(q_0q_3+q_1q_2) & 2(q_1q_3-q_0q_2) \\ 2(-q_0q_3+q_1q_2) & q_0^2-q_1^2+q_2^2-q_3^2 & 2(q_2q_3+q_0q_1) \\ 2(q_0q_2+q_1q_3) & 2(q_2q_3-q_0q_1) & q_0^2-q_1^2-q_2^2+q_3^2 \end{bmatrix} \tag{6}$$

Q is the quaternion of coordinate transformation, including a unique coordinate transformation matrix. The x, y and z directions are used to represent the front, left and up directions of the carrier. The carrier coordinate system (b system) is established, and the local horizon coordinate system is the navigation coordinate system (n system). The attitude Euler angle can be calculated from the attitude transformation matrix from n-system to b-system, and the corresponding Euler attitude matrix can be expressed as:

$$C_n^b=\begin{bmatrix} \cos\gamma\cos\psi+\sin\gamma\sin\theta\sin\psi & -\cos\gamma\sin\theta\cos\psi & -\sin\gamma\cos\theta \\ \cos\theta\sin\psi & \cos\theta\cos\psi & \sin\theta \\ \sin\gamma\cos\psi-\cos\gamma\sin\theta\sin\psi & -\sin\gamma\sin\psi-\cos\gamma\sin\theta\cos\psi & \cos\gamma\cos\theta \end{bmatrix} \tag{7}$$

In formula (7), θ, ψ and γ are pitch angle, heading angle and roll angle respectively.

The relationship between attitude quaternion and Euler angle is shown below:

$$\begin{cases} \theta = \arcsin 2(q_2q_3+q_0q_1) \\ \psi = \arctan\dfrac{2(-q_0q_3+q_1q_2)}{q_0^2-q_1^2+q_2^2-q_3^2} \\ \gamma = \arctan\dfrac{2(q_0q_2-q_1q_3)}{q_0^2-q_1^2-q_2^2+q_3^2} \end{cases} \tag{8}$$

3. Course constraint algorithm

Based on the idea of main direction in HDE, it is set that there are eight main heading directions for pedestrians in the process of walking. Because the buildings are basically structured, when pedestrians walk in the indoor environment, the course always changes around the eight main directions. When a pedestrian walks along a straight line, the heading changes little and remains within the constant range, while when the pedestrian turns, the heading will change greatly towards another main heading, which can be used to judge whether the pedestrian has turned [5].

Due to the great change of the heading angle in the process of pedestrian movement, in order to judge accurately, three consecutive steps of pedestrian heading are used to judge the direction:

$$\Delta\psi_i = \psi_i - \frac{\psi_{i-1}+\psi_{i-2}}{2} \tag{9}$$

In formula (9), ψ_i represents the heading angle at the current moment, ψ_{i-1} is the heading angle of the previous moment. When $\Delta\psi_i \le \psi_{th}$, the pedestrian is in the non steering state such as straight walking or stationary; when $\Delta\psi_i > \psi_{th}$, the pedestrian is in the turning state at time *i*. ψ_{th} is a threshold determined by repeated tests.

In the process of pedestrian movement, the difference between the current heading and the main heading is used to estimate the error of heading angle:

$$\delta\psi_i = \psi_i - \Delta[\frac{\psi_i}{\Delta}] \tag{10}$$

In formula (10), Δ represents the interval between the eight main directions of pedestrians; $\Delta[\psi_i / \Delta]$ is a rounding function.

Using EKF for error correction, the state equation is established as follows:

$$X_i = A_{i,i-1}X_{i-1} + W_{i-1} \tag{11}$$

In formula (11), $A_{i,i-1}$ is the state transition matrix of the system; $X_i = \left[\delta\psi_i, \delta v_i, \delta w_i, \delta p_i\right]^T$, $\delta\psi_i$ is attitude angle error, δv_i is velocity error, δw_i is angular velocity error, δp_i is position error; W_i is the process noise matrix of the system.

The observation equation is established as follows:

$$Z_i = H_i X_i + Q_i \tag{12}$$

In formula (12), Z_i is the observation measurement; H_i is the observation matrix; V_i is the observation noise matrix.

When the pedestrian is in a straight line or other non-turning motion state, the HDE algorithm will correct the heading error. When the pedestrian is detected to be turning, the correction will be stopped, and the cumulative heading angle error caused by the long-time operation of the inertial positioning system worn by the pedestrian is restrained.

4. Experimental verification

In this paper, the inertial positioning module developed by the laboratory is used for testing. The module can carry high-precision and low-precision inertial sensors. This test uses low-precision inertial sensors.

The experimental scene was selected on the Feng-hua playground of Chongqing University of Posts and telecommunications. The personnel walked anticlockwise according to the predetermined experimental route as shown in Figure 2. The experimental route is a rectangle 60 meters long and 40 meters wide, with a total distance of 200 meters. The reference coordinate system was established with the pedestrian's starting point as the coordinate origin, and the pedestrian returned to the starting point after walking a circle according to the predetermined experimental route.

In the test path, three turning points and terminal points are used as reference points to compare the pedestrian positioning accuracy before and after the course angle is constrained. Table 1 shows the experimental error analysis results in the case of multiple reference points.

As shown in Table 1, in the case of multiple reference points, the average positioning error of test 1 before and after correction is 5.63%, 2.09% and 3.54% respectively. The average positioning error of test 2 before and after correction is 9.22%, 2.01% and 7.21% respectively. The data show that the heading angle constraint method proposed in this paper can effectively restrain the accumulated heading angle error of low-precision inertial positioning equipment and prolong the service life of low-precision inertial positioning members.

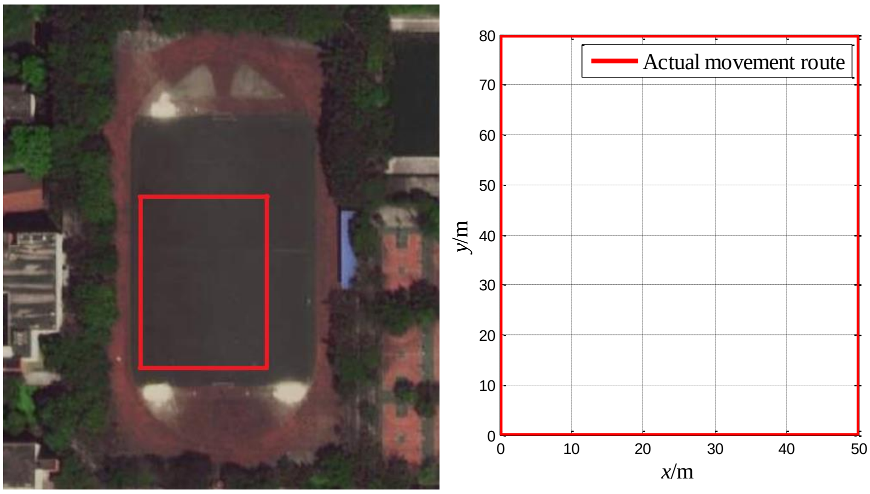

Fig. 2 Experimental route

Table 1 Error results of multi reference points in course angle constraint experiment

		Test 1			
	Actual coordinates /(m)	Coordinate before correction /(m)	Revised coordinates /(m)	Error before correction (%)	Corrected error (%)
Reference point 1	(2,78)	(6.08,79.18)	(3.04,79.29)	6.58	2.91
Reference point 2	(52,78)	(50.75,73.38)	(53.51,78.76)	4.51	1.74
Reference point 3	(52,-2)	(43.34,-6.33)	(52.57,-1.77)	6.2	1.74
Reference point 4	(2,-2)	(-0.79,8.81)	(-0.42,-4.65)	5.23	1.95
Average positioning error before correction (%)		5.63	Average positioning error after correction (%)		2.09
		Test 2			
	Actual coordinates /(m)	Coordinate before correction /(m)	Revised coordinates /(m)	Error before correction (%)	Corrected error (%)
Reference point 1	(-3,77)	(2.78,72.31)	(-3.91,78.2)	13.08	1.68
Reference point 2	(47,77)	(49.44,66.7)	(49.5,78.55)	9.8	3.11
Reference point 3	(47,-3)	(31.45,-5.96)	(48.83,-2.13)	8.81	1.29
Reference point 4	(-3,-3)	(-5.73,7.74)	(0.21,-1.05)	5.18	1.97
Average positioning error before correction (%)		9.22	Average positioning error after correction (%)		2.01

5. Summary

In this paper, the heading angle constraint method for pedestrian inertial positioning is studied. Aiming at the problem that the positioning accuracy of low-precision inertial positioning equipment is seriously divergent in a short time, a heading angle constraint algorithm for pedestrian inertial navigation is proposed. By dividing the main course of pedestrian movement environment, the deviation between the heading angle and the main heading is used to estimate the heading angle error. The experimental results show that the average positioning error of test 1 is 5.63% before correction and 2.09% after correction, and the positioning error is reduced by 3.54%. The average positioning error of test 2 before and after correction is 9.22%, 2.01% and 7.21% respectively. The experimental results show that, compared with the pure ins positioning, the multi ins cooperative positioning algorithm can effectively reduce the positioning error of the equipment members of low-precision inertial positioning equipment.

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