# Design of Indoor Pedestrian Navigation System based on MEMS

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## Abstract

This paper presents an indoor pedestrian navigation system based on MEMS inertial sensor. The system is implemented by PDR, The course estimation is based on the data fusion between gyro and electronic compass; Step size estimation is based on particle swarm optimization of the Fourier neural network step size estimation algorithm, and complete the step dynamic estimation; Pedometer adopts the step state machine based on zero rate detection error elimination to realize accurate recording . Finally , the indoor test is carried out on the rectangular route . The experimental results show that the navigation error is less than 5% of the total walking distance, which verifies the applicability and accuracy of the navigation algorithm and satisfies the pedestrian navigation requirements .

## Keywords

MEMS, PDR, Step estimation.

## 1. Introduction

Pedestrian navigation system can provide navigation location information for pedestrians, including relative geographic position information and latitude and longitude position information. At present the global positioning system plays an important role in the pedestrian navigation system, but in the modern city of skyscrapers, especially indoor, tunnel and other weak signal place, GPS has been unable to satisfy people's needs [1]. At the same time, the smart city and home provides a new development prospect for indoor positioning and navigation. Now the main indoor positioning and navigation technology consist of WIFI, RFID, ZigBee, WSN and INS etc. An inertial navigation system (INS) is a navigation aid that uses a computer, motion sensors and rotation sensors to continuously calculate via dead reckoning the position, orientation, and velocity of a moving object without the need for external references [2]. Compared with other indoor navigation methods, pedestrian inertial navigation has the advantages of small size, low power consumption, easy installation and high precision. The MEMS sensor has developed rapidly in recent years, and the cost is greatly reduced, this makes the MEMS inertial device has become an ideal choice for pedestrian navigation.

Currently, there are two main approaches: One is method of the traditional strap down inertial navigation, the inertial measurement unit is fixed on the human body, by means of processing the acceleration and angular rate of the output of the inertial measurement unit, the attitude information and position of the pedestrian are predicted by using the method of calman filter and zero velocity detection [3].

The traditional strap down inertial navigation system is used for pedestrian navigation in literature [4], the final error is 5.6%. Literature [5] uses extended calman filter and eliminate indoor local magnetic field interference method for pedestrian indoor navigation, the final error control in 4.8%. Literature

[6] uses complementary filtering data fusion and gait detection method to obtain trajectory, error control in 4.4%.

The other is using method of pedestrian dead reckoning (PDR) .First, the inertial measurement unit collect pedestrian dead reckoning data, and then judge the walking steps, step length and walking direction, thereby calculating the pedestrian position [7]. This method usually has the advantages of high accuracy, low cost, strong applicability etc. [8]. Therefore, this paper uses PDR method to analyze pedestrian gait characteristics, and uses the algorithm to optimize the step size, step number and course respectively, then integrates the three points to achieve pedestrian indoor navigation.

## 2. The Navigation System

This paper studies the pedestrian dead reckoning system ,structure diagram as shown in figure 1.The course estimation is based on the data fusion between gyro and electronic compass ; Step size estimation is based on Particle Swarm Optimization of the Fourier neural network step size estimation algorithm, and complete the step dynamic estimation, the algorithm has fast convergence speed and good characteristics of nonlinear fitting character ; Pedometer adopts the step state machine based on zero rate detection error elimination to realize accurate recording . The navigation system hardware platform using MPU-6050 and HMC-5883L as the navigation sensor, Arduino as navigation processor, building the system of measurement.

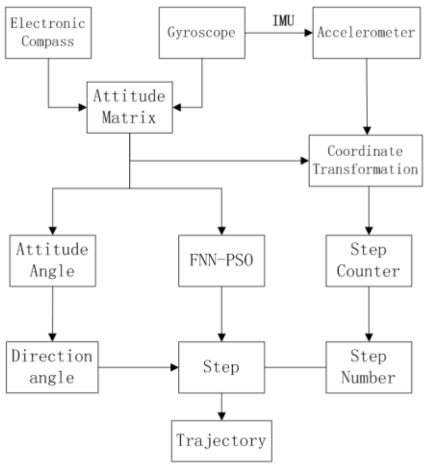


Fig. 1 Scheme design flow chart

## 3. Pedestrian Dead Reckoning

### 3.1 Direction angle judgment

Gyroscope uses inertia principle, the outside of its output interference is little, but it has zero drift error; the electronic compass determines the attitude angle by using the three axis geomagnetic field intensity, which without zero drift error. If the attitude angles of the two outputs are weighted and fused, the data reliability can be improved effectively.

Suppose that attitude angle of gyroscopes is $A_g$ ,attitude angle of electronic compass is $A_c$ ,gyro attitude angle accounted for $n_g$ , electronic compass attitude angle accounted for $n_c$ , so weighted fusion attitude angle $A$ is

$$A = \frac{n_g A_g + n_c A_c}{n_g + n_c} = N\left(A_c - A_g\right) + A_g \tag{1}$$

Where

$$N = \frac{n_c}{n_g + n_c} \tag{2}$$

### 3.2 Step size estimation

Step size estimation using Fourier neural network algorithm based on particle swarm optimization, particle swarm optimization is used to optimize the output weights of the Fourier neural network, it makes the convergence of *PSO* fast and the nonlinear fitting ability of Fourier neural network strong, finally get better performance of the algorithm framework [9].The particle velocity and position update methods in the algorithm are as follows

$$\begin{cases} V_{id}^{k+1} = wV_{id}^{k} + c_1 r_1 (P_{id}^{k} - X_{id}^{k}) + c_2 r_2 (P_{gd}^{k} - X_{id}^{k}) \\ X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \end{cases} \tag{3}$$

Where $w$ is the inertia weight, $d$=1, 2,..., $D$ represent dimension; $i$=1, 2,..., $n$ represent the particles; $k$ is the current iteration; $r_1$、$r_2$ is random number between [0, 1]; $c_1$ and $c_2$ is a nonnegative constant, which called acceleration factor; $V_i$ represents the particle velocity, and $X_i$ represent the particles the position; $P_i$ represents the optimal value; $P_g$ represents the global optimal value. Using the above formula, the global optimal solution can be determined by iteration.

### 3.3 Step by step algorithm

The method adopts zero speed detection and step by step state machine.

3.3.1 Zero velocity detection

Zero speed detection using foothold to judge.

The total acceleration amplitude of accelerometer output is between two thresholds when the foot is landing.

$$C_1 = \begin{cases} 1 & th_{a_{\min}} < |\mathbf{a}_k| < th_{a_{\max}} \\ 0 & otherwise \end{cases} \tag{4}$$

$$\begin{aligned} |\mathbf{a}_k| &= [\mathbf{a}_k^b(1)^2 + \mathbf{a}_k^b(2)^2 + \mathbf{a}_k^b(3)^2]^{\frac{1}{2}} \\ th_{a_{\min}} &= 9m/s^2 \\ th_{a_{\max}} &= 11m/s^2 \end{aligned} \tag{5}$$

The total angular velocity amplitude of gyro output value is below a threshold when the foot is landing.

$$C_2 = \begin{cases} 1 & |\boldsymbol{\omega}_k| < th_{\omega_{\max}} \\ 0 & otherwise \end{cases} \tag{6}$$

$$\begin{aligned} |\boldsymbol{\omega}_k| &= [\boldsymbol{\omega}_k^b(1)^2 + \boldsymbol{\omega}_k^b(2)^2 + \boldsymbol{\omega}_k^b(3)^2]^{\frac{1}{2}} \\ th_{\omega_{\max}} &= 50^\circ/s \end{aligned} \tag{7}$$

The total acceleration variance of accelerometer output is below a threshold when the foot is landing.

$$C_3 = \begin{cases} 1 & \sigma_{a_k}^2 < th_{\sigma_{\max}} \\ 0 & otherwise \end{cases} \tag{8}$$

$$\begin{aligned} \sigma_{a_k}^2 &= \frac{1}{2s+1}\sum_{j=k-s}^{k+s} (a_j^b - \overline{a_k^b})^2 \\ \overline{a_k^b} &= \frac{1}{2s+1}\sum_{q=k-s}^{k+s} a_q^b \\ th_{\sigma_{\max}} &= 10.2 \end{aligned} \tag{9}$$

The above three conditions of the logic "and" operation to get the final landing site.If the $C$ is 1, indicating that the foot is indeed landing, else foot is not landing.

$$C = C_1 \& C_2 \& C_3 \quad (10)$$

3.3.2 Step state machine

Step state machine using slope to judge. Calculate the slope of $X$, $Y$, $Z$ acceleration, do a forward difference, and filtering to remove the noise, the slope positive value marked +1, the slope negative value marked -1, the other marked 0. Figure 2 is the number of steps of statistical chart, each step upward, and a cumulative.

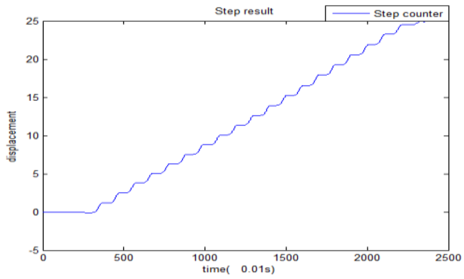


Fig. 2 Step number statistics

## 4. Experimental result

The direction angle judgment, step estimation and step integration are integrated to obtain the complete pedestrian navigation trajectory. In order to verify the feasibility of the pedestrian navigation system designed in this paper, the rectangular route is carried out indoors, as shown in Figure 3 dotted line. From the track can be seen in the figure, the basic foothold falls within a predetermined trajectory, the maximum deviation is 0.3 meters, and the calculation error is 4.3%.

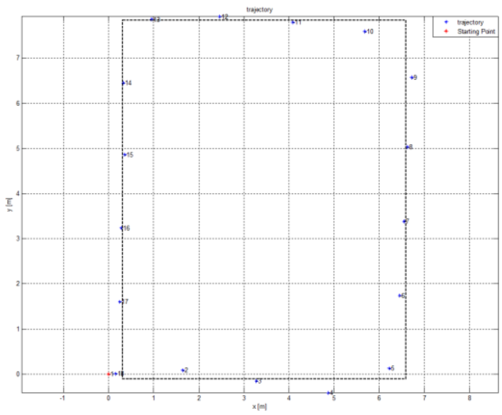

Fig. 3 Test results chart

## 5. Conclusion

This paper uses MEMS of low accuracy inertial sensors, and analysis of gait characteristics of pedestrian, calculate PDR inertial navigation by the pedestrian, and finally realize the indoor navigation. There is a delay in the navigation process, the reason is that the sensor needs to collect data, then upload to the MATALB software, and calculate via MATALB the trajectory, form the delay. How to reduce the delay time is become the next target.

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